Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

January 1961

A-O's Industrial Plant of Merit

Effects of Heated Discharges On a River

ASME Annual Meeting Highlights

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 32 number 7 **January 1961**

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BPA

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COVER PHOTO

Attractive view of the Porcheville power plant of the Electricite de France on the Seine River, near Paris

American Optical Takes First Industrial Power Plant Award of Merit . . . 24

A. W. Hindenlang

This report on the first COMBUSTION Award of Merit for industrial power plants describes the award winning plant of American Optical Co. at Southbridge, Massachusetts

Memories of the Good Old Days . . . 35

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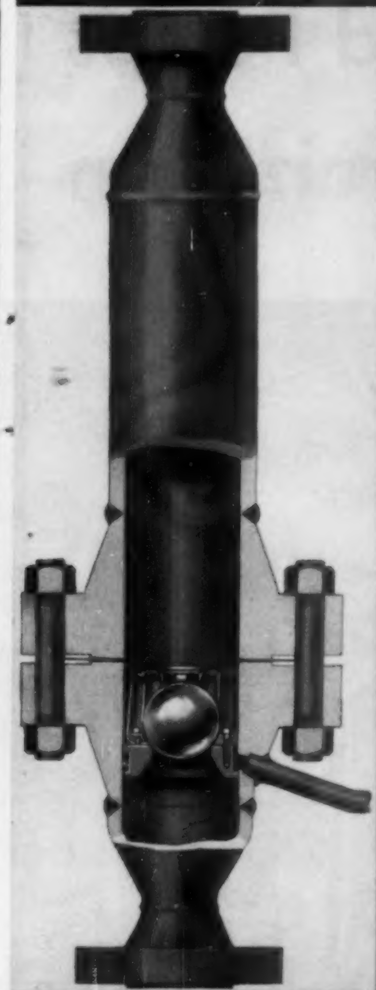
H. J. Heinz relies on Copes-Vulcan reducing and desuperheating station to handle big changes in steam demand



(Far left) **Chart on left side of panel** shows wide load changes. Chart on right indicates exacting pressure and temperature control. Station takes boiler steam at 600 psig and 750 degrees F. and delivers it to process at 110 psig and 360 degrees F.

(Cutaway at left) **A weighted steel ball controls orifice opening**, speeds intimate mixing of cooling-water and steam. No atomizing steam, spray nozzle, or glands required. Write for Bulletin 1037.

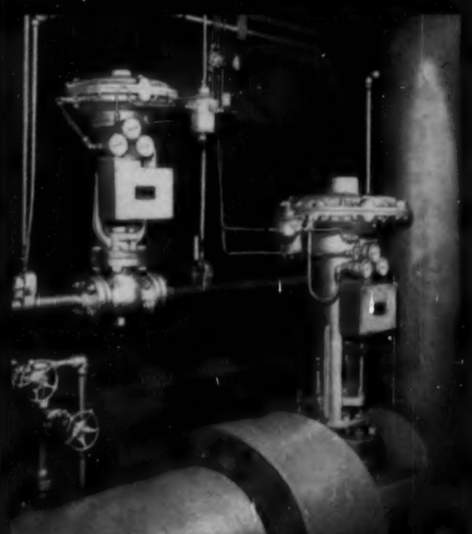
(Upper right) **The 8-inch, 300-pound pressure desuperheater** is installed in the insulated vertical run of steam piping at the far left. The cooling-water control valve is behind the pressure reducing valve in the right foreground.

Fast acting valves assure rigid control

Cooling water flow for the desuperheater is controlled by a 1-inch, 300-pound standard Type CV-D diaphragm valve (left) actuated by a temperature controller.

The 600-pound standard Type CV-D reducing valve (right) has a 4-inch inlet and 8-inch outlet to take care of steam expansion at reduced pressure. Its positioner assures accurate control modulation.

Copes-Vulcan diaphragm type valves can be direct or reverse acting. Piston types are also available for high duty service, assure maximum power with precise positioning. Write for Bulletin 1027.



Working with flow rates that vary from 0 to 70,000 pounds per hour, this Copes-Vulcan reducing and desuperheating station holds process steam to plus-or-minus 4 psig and plus-or-minus 5 degrees F. with only 16 degrees F. superheat. Wide fluctuations in steam requirements often occur extremely rapidly at the H. J. Heinz plant in Pittsburgh. On a typical day, the load increased from 0 to 47,000 pounds per hour within 15 minutes, then dropped back to 5,000 pounds per hour in even less time.

Made up of a Copes-Vulcan Variable-Orifice desuperheater and diaphragm operated Type CV-D valve, this type of station represents a new approach in process steam control. Since its installation over a year ago, the station has maintained an outstanding record for continuous accuracy.

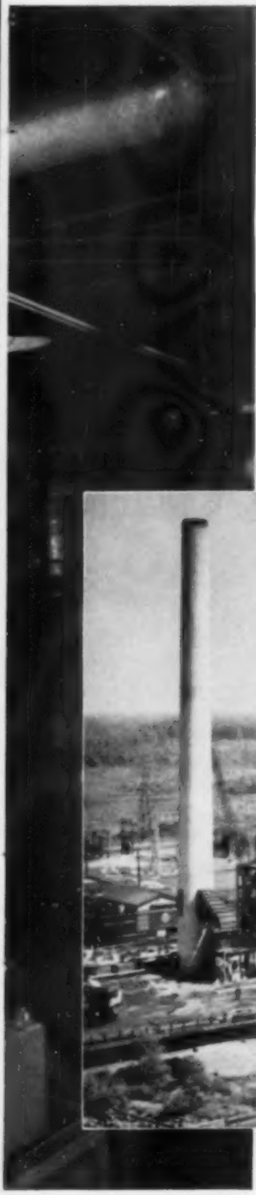
Whatever your operating conditions, Copes-Vulcan has the desuperheating station for controlling your reduced steam temperatures. Besides the Variable-Orifice type, the line includes a Steam-Assist type and a Carburetor type. Write for details.

Copes-Vulcan Division, Erie 4, Pennsylvania.

Copes-Vulcan Division

BLAW-KNOX

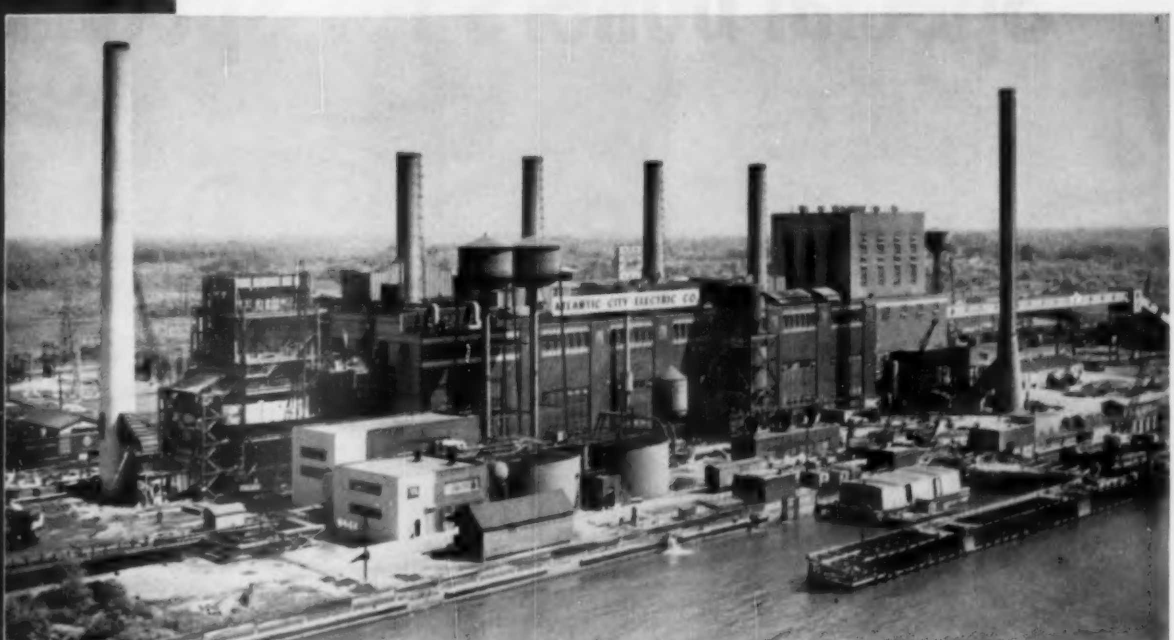
at Atlantic City Electric



Gibbs & Hill, Inc., Consulting Engineers, handled project for new 79,000 KW unit

To meet increased load demand while improving station performance, Atlantic City Electric has completed the installation of a new 79,000 KW No. 1 main unit at Deepwater Station, the largest now operating in their system.

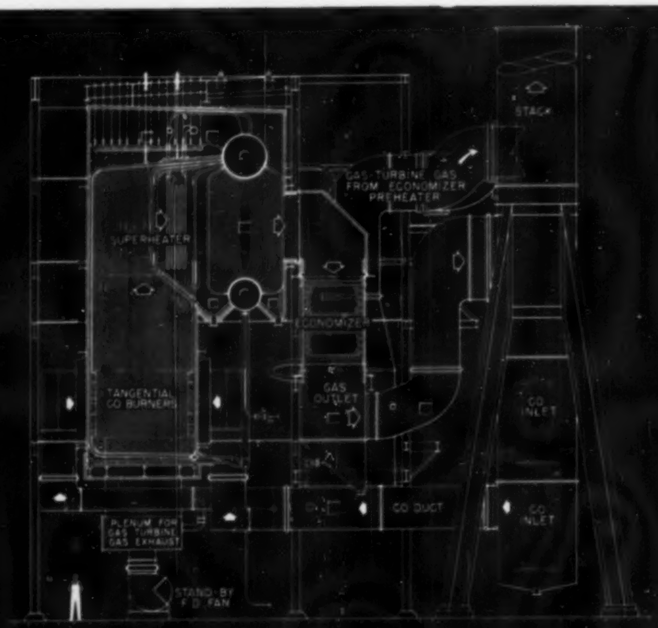
Providing dependable boiler feed service are two 1000 HP direct motor driven half capacity De Laval barrel feed pumps, now in their second year of operation. This is the second modern installation at Deepwater to be served by De Laval barrel pumps.



Deepwater Station at the southern extremity of the N. J. Turnpike.

DE LAVAL STEAM TURBINE COMPANY

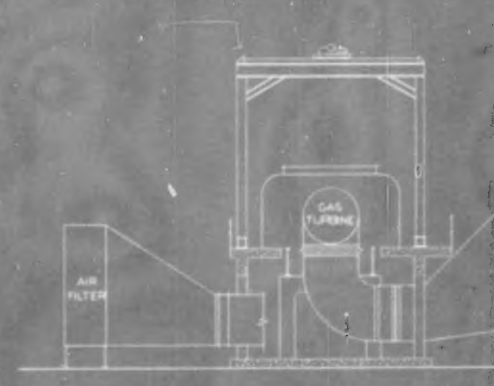
NOTTINGHAM WAY, TRENTON 2, N. J.

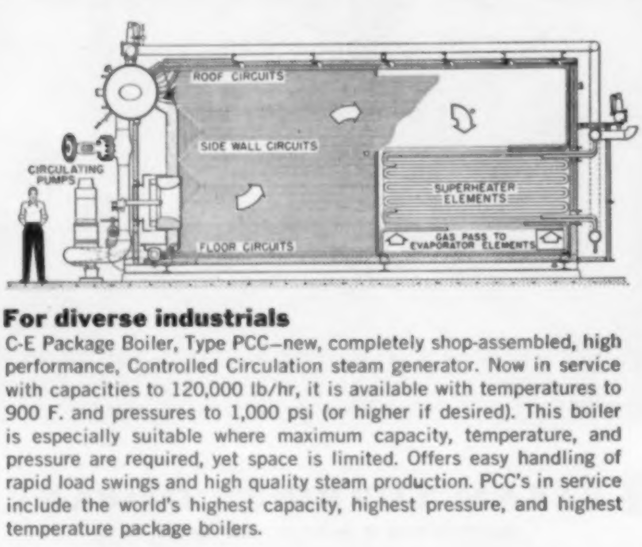


For refineries

C-E Vertical Unit Boiler, Type VU-40 CO – tangentially fired boilers to efficiently utilize energy potential in hard-to-burn waste catalyst regenerator gas. Illustrated is an installation at a Gulf Coast refinery. It combines a catalyst regenerator, two gas turbine-driven compressors, two CO boilers, and separate turbine-exhaust-gas feedwater heaters located between the boilers. Available in a wide range of sizes for any quantity of catalyst regenerator gas and for any steam capacity, CO Boilers by C-E have been in service more than three years.

Special boilers for special





For diverse industrials

C-E Package Boiler, Type PCC—new, completely shop-assembled, high performance, Controlled Circulation steam generator. Now in service with capacities to 120,000 lb/hr, it is available with temperatures to 900 F. and pressures to 1,000 psi (or higher if desired). This boiler is especially suitable where maximum capacity, temperature, and pressure are required, yet space is limited. Offers easy handling of rapid load swings and high quality steam production. PCC's in service include the world's highest capacity, highest pressure, and highest temperature package boilers.

C-E builds boilers of virtually all designs and types known in present practice . . . in capacities from less than 10,000 to 4,000,000 or more lb. of steam per hr. It is presently building units that will set new world records for capacity, pressure and temperature.

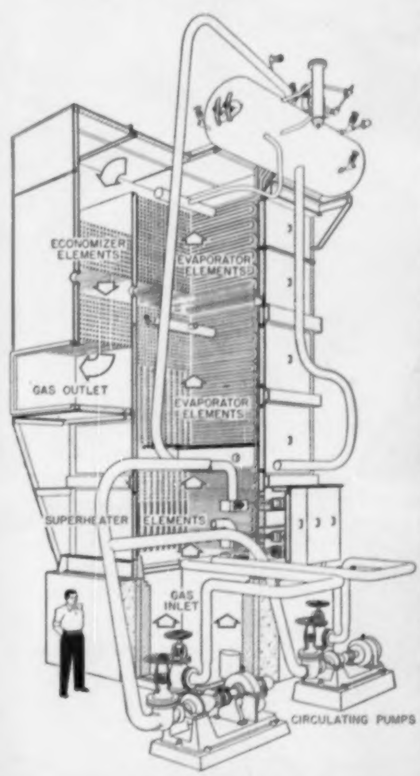
This vast experience has also been successfully applied to the development of many special designs to utilize waste fuels or to meet unusual steam requirements or space conditions.

A few recent examples of special C-E designs which have successfully met unusual problems are illustrated here. In several cases, this success may be attributed to the utilization of exclusive C-E developments such as controlled circulation or tangential firing.

Whether your requirements call for boilers of unusual characteristics, such as those shown here, or for more conventional standard designs, come to C-E where you'll find the skill, experience, facilities—and desire—to meet your needs *exactly*.

For the steel and chemical industries

C-E Package Boiler, Type WCC—a Controlled Circulation design which utilizes waste heat from open hearths or chemical processes. The platen surfaces featured in the first pass permit passage of abrasive or "sticky" gas without erosion or bridging, prolonging boiler life and making the unit easier to clean. Controlled Circulation assures positive control of water to all circuits, permitting a smaller boiler with obvious space-saving advantages. Seven WCC's are now in service; eight others are being erected.



needs — by C-E

For gas turbine installations

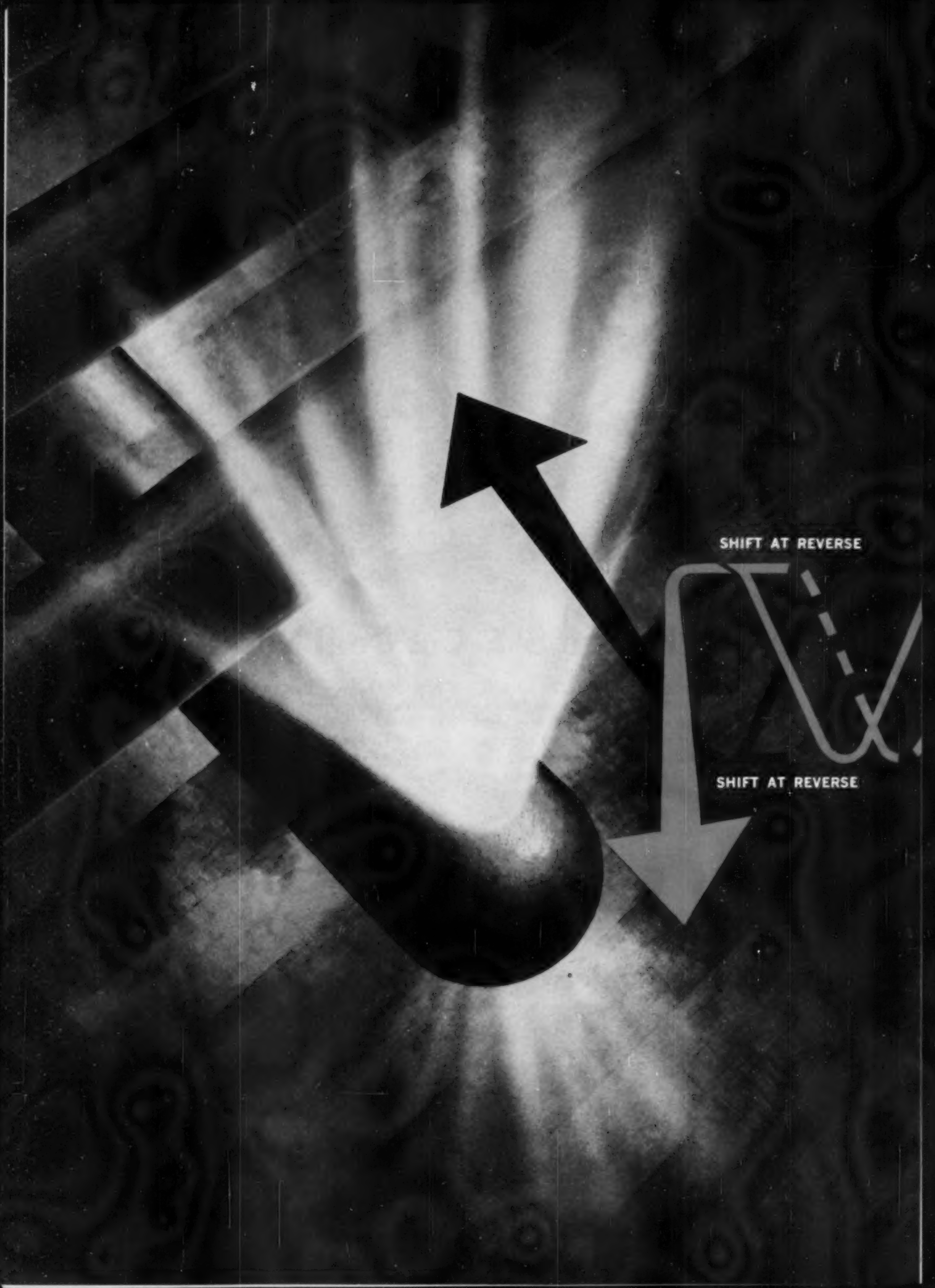
C-E Gas Turbine Boiler—waste heat design for economical utilization of gas turbine exhaust sensible heat. Usable in a choice of cycles to obtain fired or unfired heat recovery and steam generation. Illustrated is a combined cycle, two of which are in service at a chemical plant. Here the turbine is followed by a waste heat boiler, multiple-purpose economizers (process and feedwater), and a conventional oil-fired steam generator which uses a portion of the high temperature exhaust gas for combustion air.

COMBUSTION ENGINEERING

General Office: Windsor Conn.: New York Offices: 200 Madison Ave., N. Y. 16, N. Y.

C-195

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

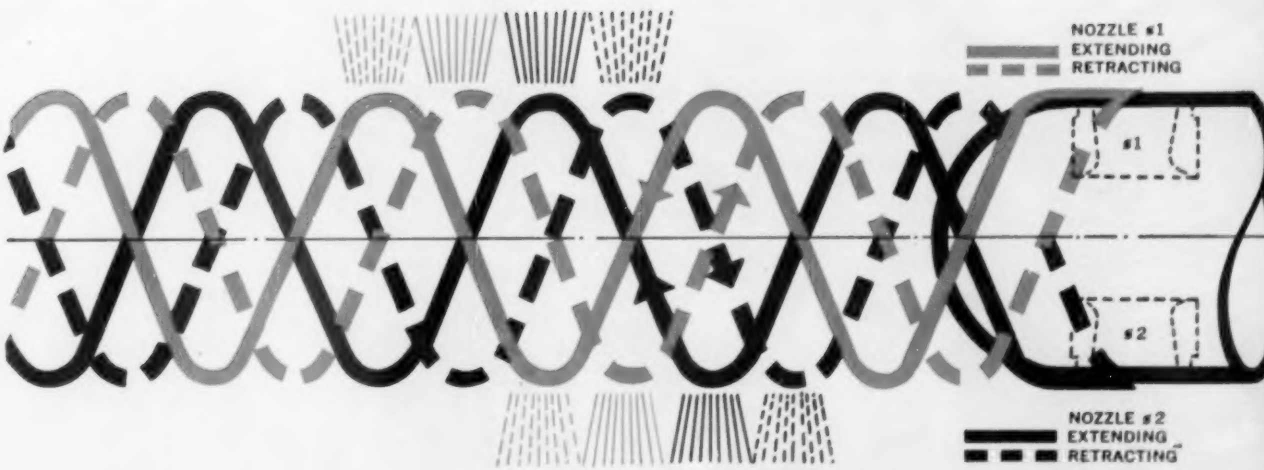

SHIFT AT REVERSE
SHIFT AT REVERSE

Diamond developed for more economical power...

A CLEAN SWEEP...EVERY INCH OF THE WAY

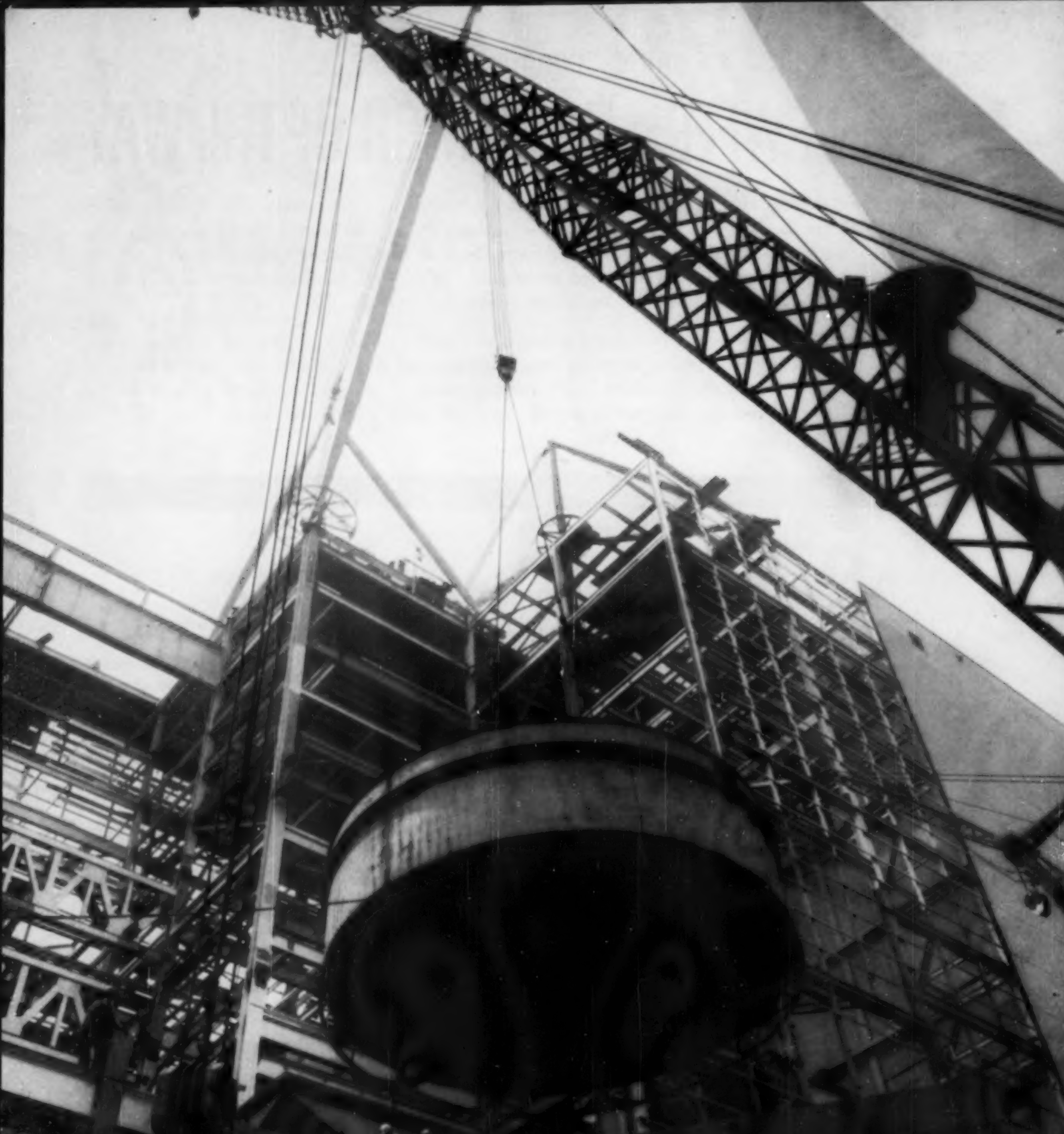
Get uniform, complete cleaning in those "tough-to-clean" zones. Specify Diamond's IK-300 Retractable Blower. The exclusive close-spaced IK helix assures a penetrating nozzle sweep every inch of travel regardless of tube bank arrangement and tube spacing. What's more, because sectionalized lance tube construction cuts deflection to a minimum, smaller boiler cavities are possible. In addition, a unique method of equalizing nozzle end-thrust assures "minimum-wobble" travel regardless of distance.

IK's are just part of the reason behind Diamond's established superiority in boiler cleaning systems. Add a complete line of cleaning equipment, an experienced, imaginative engineering staff and an unmatched service organization. No wonder thousands of utility and industrial power plants are equipped with Diamond Cleaning Systems — engineered and designed to provide you with more economical power.



Diamond

DIAMOND POWER SPECIALTY CORPORATION, Lancaster, Ohio • **DIAMOND SPECIALTY LIMITED,** Windsor, Ontario



IN WISCONSIN...

OAK CREEK PLANT INSTALLS ITS 14th LJUNGSTROM®

Three new Ljungstrom Air Preheaters are being added to the eleven already in service at Wisconsin Electric Power Company's Oak Creek plant. These three 290-ton units will serve the 1,780,000 lb/hr boiler on Oak Creek's #6 unit. The three Ljungstroms, with a total heating surface of 795,300 sq ft, will reduce stack gas temperature from 550°F to about 270°F and preheat incoming combustion air from 190°F to about 510°F.

Our engineers will be glad to recommend how Air Preheater equipment can improve your operating results on new or existing fuel fired units.

THE AIR PREHEATER CORPORATION

60 East 42nd Street, New York 17, N. Y.

new Yarway Unit Tandem Valve for blow-off service up to 665 WSP . . . gives you the same time-proven dependability of the famous 1500 and 2500 WSP Yarway Unit Tandem design. Streamlined, light in weight, easy to operate, tight sealing, with minimum maintenance.

Ask for free Bulletin B-435, Supplement A

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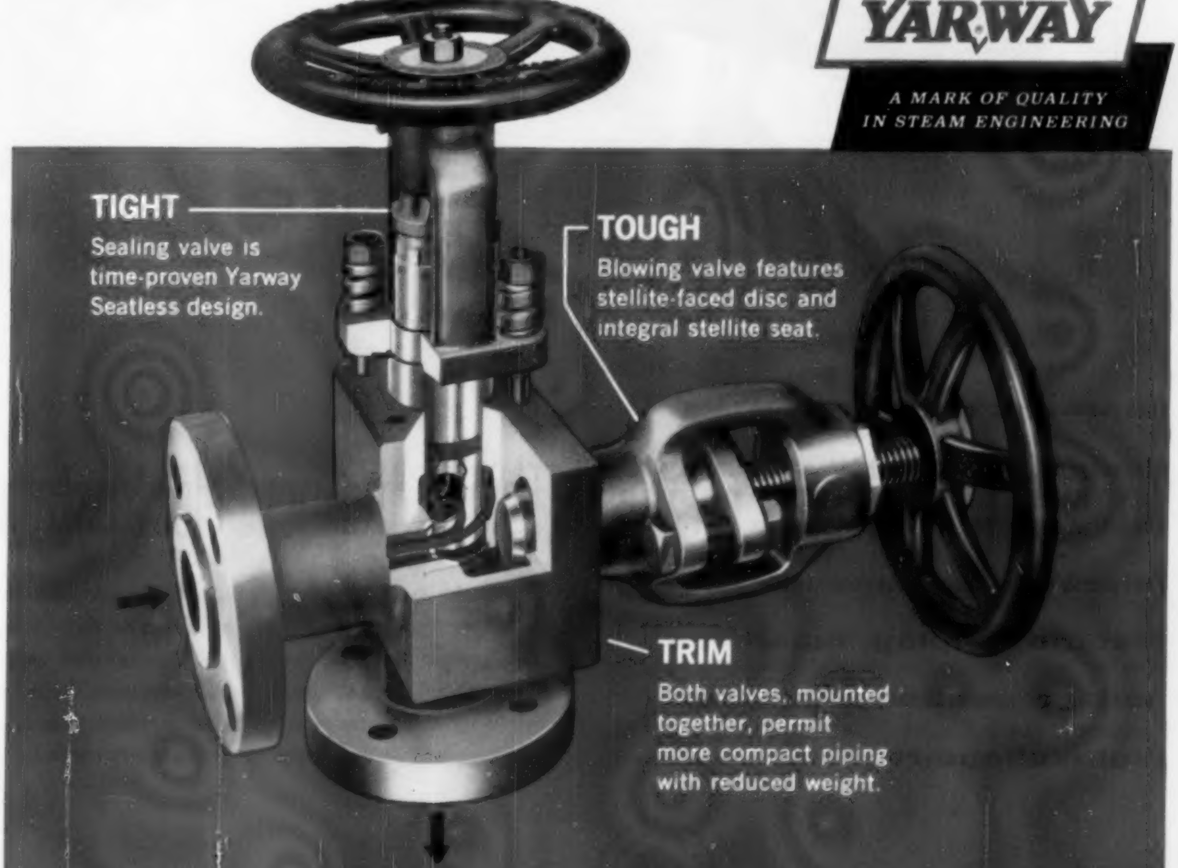
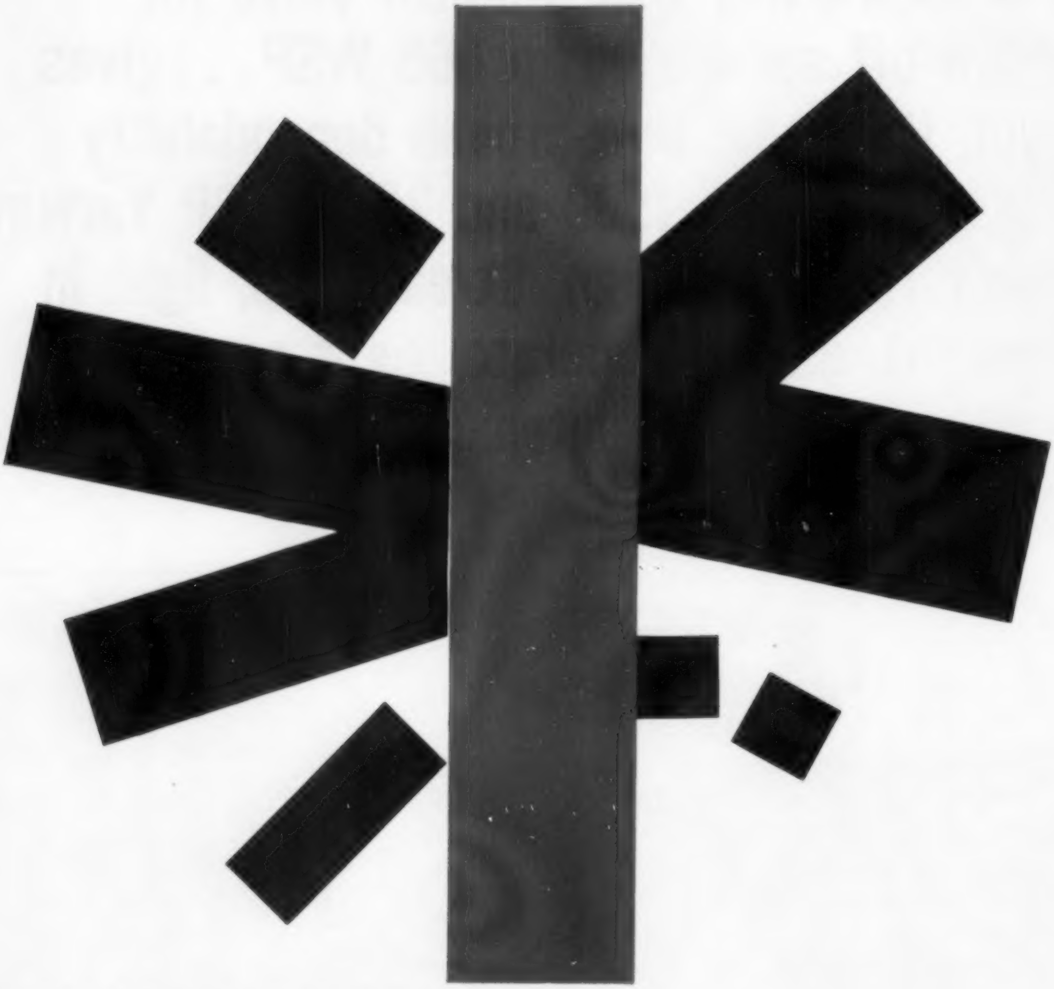
YARWAY
A MARK OF QUALITY IN STEAM ENGINEERING



A FEW OF THE MANY SATISFIED USERS: U. S. Sugar Corp. • West Point Mfg. Co. • Halifax Paper Co. • R. J. Reynolds Tobacco Co. • Pulp and Paper Co., Colombia, S. A. • Western Electric Co. • Cornell University

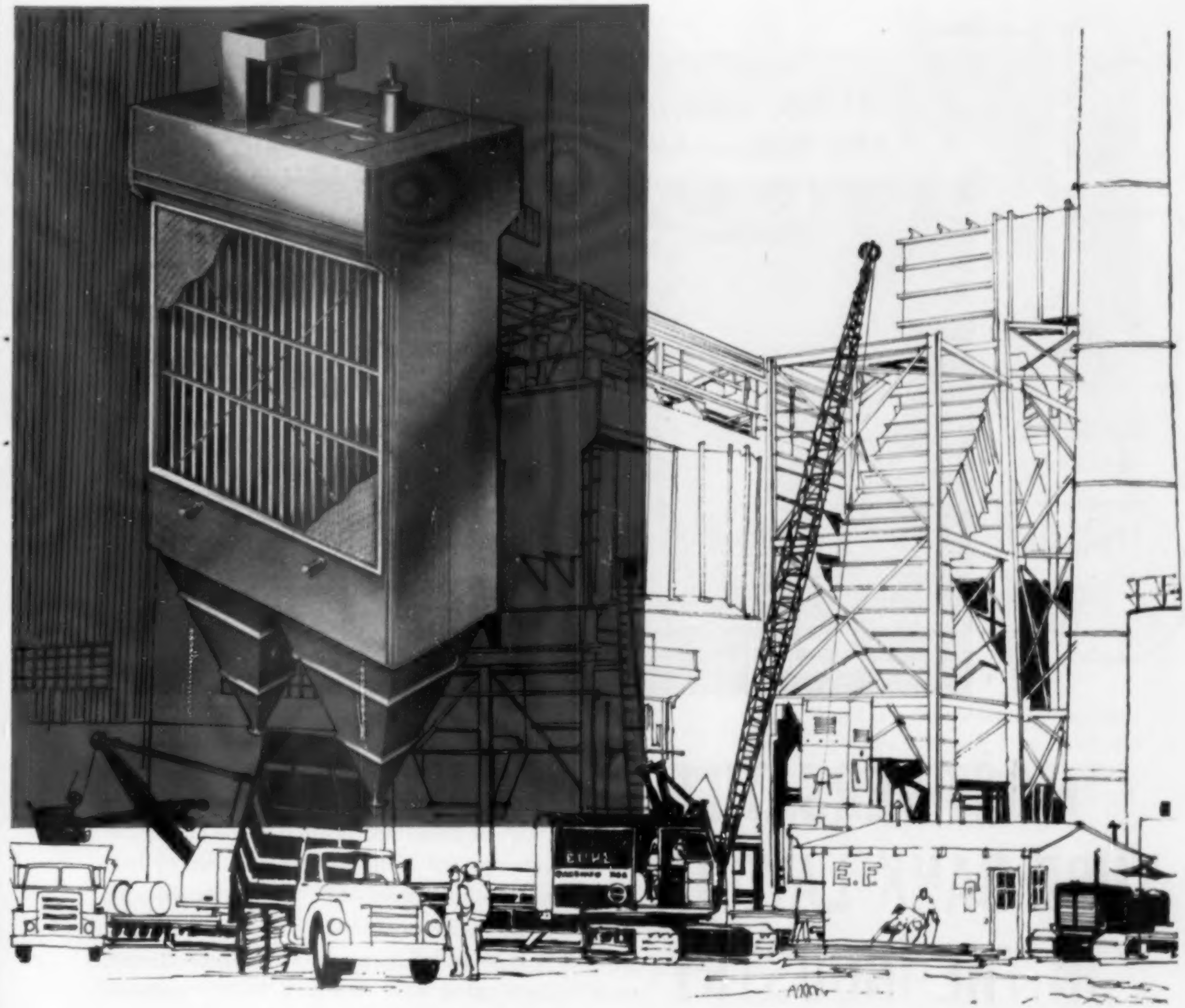
POSITIVE COLLECTOR PLATES ATTRACT NEGATIVE DUST PARTICLES



improved collector plate design, factory pre-assembly that cuts field erection time, improved pneumatic or electric rapping, automatic voltage control, choice of high-voltage rectifiers

This is the new electrostatic

One of the most important features of our new electrostatic precipitator is the unique new collector plate. It is a flat plate to which we have added a "pocket" that traps dust, and reduces the chance of reentrainment. The new design also improves clean-plate sparking voltage, increases the migration velocity of particles, performs better with high

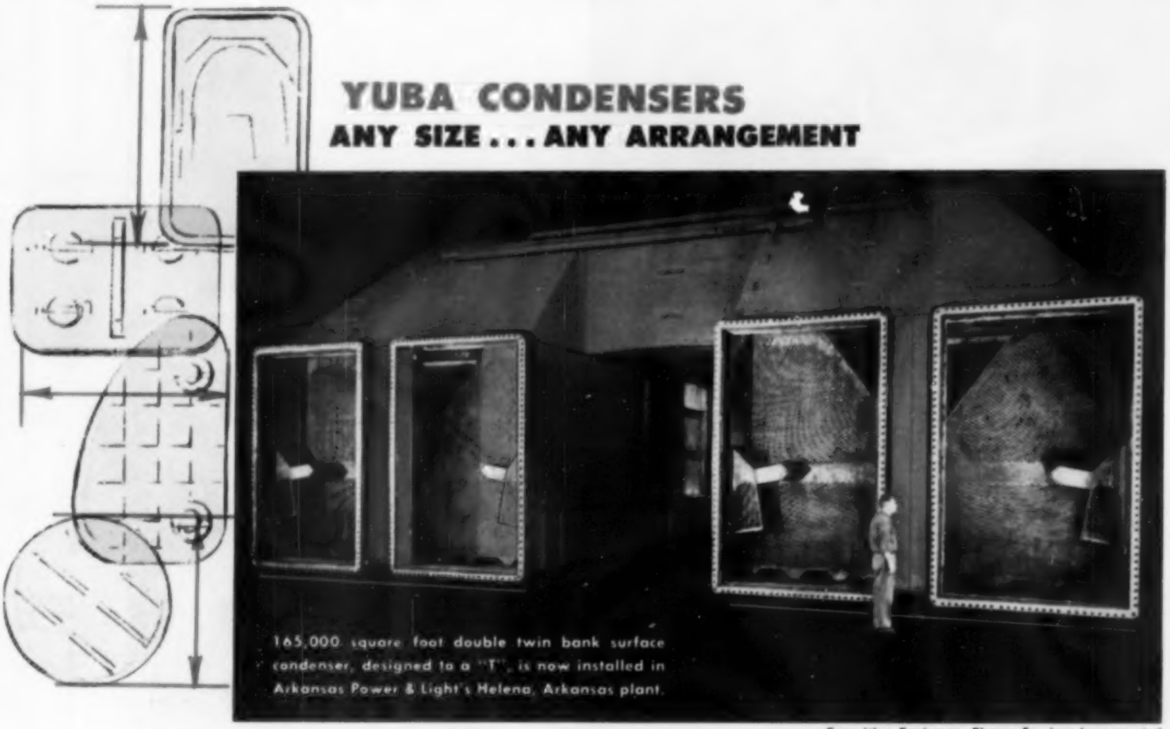


precipitator from American-Standard Industrial Division!

resistivity dusts, and makes rapping much easier. The choice of rapper is up to you; we offer both pneumatic and electric types. So is the choice of rectifier . . . silicon, selenium, high-voltage vacuum, or mechanical. Automatic voltage control is standard with all units. Factory pre-assembly is carried to the limit of practicality. Case in point: Structural frames, side casing, end panels, and hoppers arrive ready to drop in place. The result is faster, less costly field erection. For detailed information, call our nearest sales office and talk with one of our product specialists. American-Standard Industrial Division, Detroit 32, Mich. In Canada: American-Standard Products (Canada) Limited, Toronto, Ontario.

AMERICAN-Standard
INDUSTRIAL DIVISION
SALES OFFICES IN ALL PRINCIPAL CITIES

YUBA CONDENSERS
ANY SIZE . . . ANY ARRANGEMENT


165,000 square foot double twin bank surface condenser, designed to a "T", is now installed in Arkansas Power & Light's Helena, Arkansas plant.

Consulting Engineers: Ebasco Services Incorporated

MOST VERSATILE TUBE BANK LAYOUT IN THE INDUSTRY

YUBA SURFACE CONDENSER DESIGN . . . most flexible . . . any size . . . any arrangement. Through design advances such as those incorporated in the unit above, Yuba illustrates the concepts you can expect from years of engineering leadership in the power industry.

Yuba's twin-bank tube layout, seen here in a two shell "T" type installation, promotes unobstructed, equally distributed flow. Through Yuba's patented design, the condensate can be deaerated with oxygen content guaranteed to be less than 0.005 cc per liter.

As a design extra, Yuba staggers the tube support plates – reducing harmonics – eliminating vibration. These are some of the reasons why Yuba surface condensers of all sizes have been installed in plants throughout the world. You'll want to know more about the most versatile tube bank layout in the industry – contact Yuba today.

Other Yuba products for steam power plants include feedwater heaters, evaporators, expansion joints, cranes, tanks, structural steel erection, and scores of other items.

YUBA

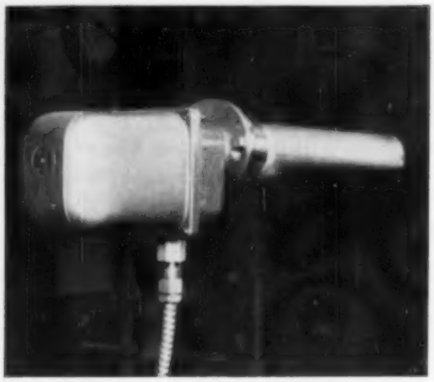
specialists in power plant equipment

YUBA HEAT TRANSFER DIVISION

YUBA CONSOLIDATED INDUSTRIES, INC.

SALES OFFICES IN PRINCIPAL CITIES

Now…new from Bailey …a "foolproof" FLAME DETECTOR



that rejects flames from other burners

Flame detectors are sometimes "fooled" by glowing refractories or flames from burners adjacent to that under surveillance. This new Bailey Flame Detector *responds only to the flame it surveys* . . . assures positive monitoring of coal, gas, oil or combination fuel-fired furnaces. Absence or failure of flame is sensed and accurately signaled—or relayed to control auxiliaries—without use of external relays or amplifiers.

Here are other distinctive features that make this new Bailey Flame Detector outstanding:

Wide temperature range . . . is suitable for use in areas with ambient temperatures from -20 to +300° F. Flame sensing element withstands temperatures up to 600° F.

Easy inspection . . . quick disconnect, keyhole mounting simplifies checking of lens condition and detector alignment.

Simple, solid-state circuitry . . . Bailey Flame Detector unit contains only 8 components.

Weatherproof construction . . . design of Bailey unit makes it suitable for outdoor installation.

Why not have your Bailey Engineer give you more information? Call the Bailey district office, or write us.

A147-1

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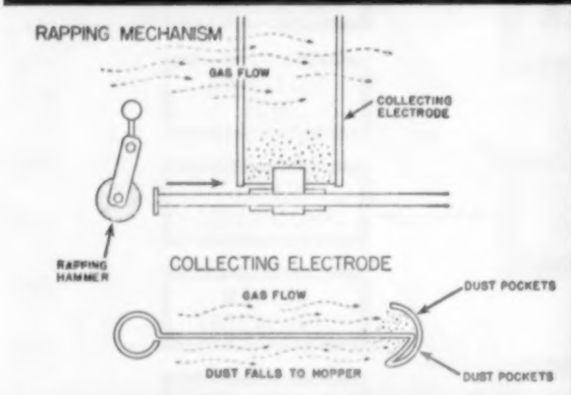
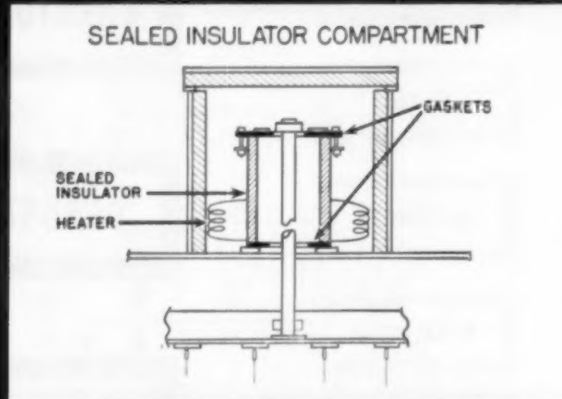
SOME PLAIN FACTS

ABOUT SUPERIOR PRECIPITATOR PERFORMANCE

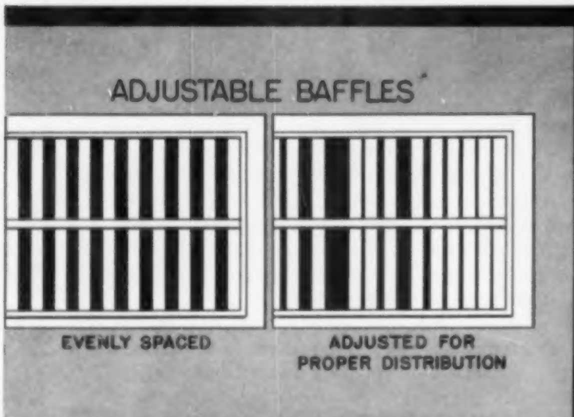
Buell Precipitators are designed and constructed for rugged service and superior performance. Frills and internal frim-fram of a doubtful value are eliminated in favor of strength and simplicity. The casing, outside supports, and internal parts are of rugged construction; and the four-point suspension of emitting electrodes ensures the greatest stability. Here are just a few of the outstanding features of Buell Precipitators.



Effective Continuous Cycle Rapping—Yes, it's mechanical. A simple, rugged system free of complicated gadgets; assures positive dust shearing action. Each row of electrodes is rapped separately—in the direction of the gas flow—on a continuous cycle. Dust is sheared off, drops in an agglomerated mass and pockets on electrodes minimize reentrainment.



Sealed Insulators Improves Operation—High voltage quartz support insulators are completely sealed; prevents gas and dust leaking into insulator compartment and outside air leaking into precipitator. There is no need for costly ventilating systems. Thermostatically controlled electric heaters insure start-up without danger of moisture condensation and insulator breakdown.



Uniform Distribution of Gas Flow—Field adjustment capability is vital. Buell's adjustable baffle permits final positioning after field measurement of actual flow distribution . . . because gas flow patterns are not entirely predictable. The Buell distribution system assures equal gas loading through the precipitator; eliminates ineffective "dead" areas around passages and prevents "sneak-by."

Buell Spiralectrodes cut maintenance to a minimum. Buell's record stands at less than 1% replacement in this key area. Self-tensioned spiralectrodes eliminate vibration and "off-center" swaying, often prevalent with weight-tensioned wires. They're structurally fixed and once installed stay in alignment. The spiralectrode provides greater emission than straight wires.

Buell precipitators are simple and effective. They're designed for continuous service. You'll be glad you turned to Buell when you experience superior performance and low maintenance. Detailed literature describing all features is available.

buell Norblo

The Buell Engineering Co., Inc., Dept. 70-A, 123 William Street, New York 38, N. Y. Northern Blower Division, 6413 Barberton Avenue., Cleveland, Ohio. ■Electric Precipitators ■Cyclones ■Bag Collectors ■Combination Systems ■Fans ■Classifiers.

Combustion

EDITORIAL

Shakedown for Automation

Exploratory attempts within the power industry to advance the art of steam raising or power generation have traditionally been made community knowledge. Whatever operating company decides to place its company dollars on the line to apply a new design, a new operating aid to its plant, that company usually lays open its experiences to all interested. This remarkably free exchange of ideas and know how has tended to make the initial acceptance of something new a somewhat slow process within the power industry. The pressure of a possible operating advantage that the new technique might offer the early users does not exist. The risk of the shakedown is assumed by relatively few but the knowledge the shakedown gives is shared by all. Automation in the power industry is undergoing this very process today.

Other industries do not, however, follow this procedure. *The Wall Street Journal* of Dec. 27, 1960, gives an interesting account of the shakedown process automation is experiencing in other fields. One such—a butane making plant—which had been turned over to computer operation to obtain an expected better control over the two major variables of steam flow and raw material suffered some severe operating headaches because the computer could not recognize nor cope with shortages of steam or valve breakdowns. Still another somewhat similar incident occurred at the Ballistic Missile Early Warning System station in Greenland. The computer-controlled radar set-up indicated a missile attack had been launched against North America. Technicians found out the signals had come from the rising moon whose appearance completely baffled the station's computer. Both of these failures have been attributed to the fact that the computers had not been properly programmed.

If there is any moral to the above account it is the one the utility industry has always lived by—"and men must walk, at least, before they dance." Automation will certainly assume larger responsibilities in the power plants of the future but only after it has passed the industry's yardsticks of reliability and economy. We look forward to Little Gypsy, Huntington Beach and Alamitos stations.

	Average	Good	Outstanding
Efficient, Reliable Operation			✓
Housekeeping and Maintenance			✓
Records			✓
Ingenuity in Solving Problems			✓
Checks on Performance			✓
Morale			✓

American Optical Takes First Industrial Power

We visited Southbridge primarily to do another story but were so impressed by the plant and its operation that we felt impelled to give public recognition to so high a caliber of performance. The Award of Merit idea was conceived on the spot. What are the things we look for in making a COMBUSTION Award of Merit? Table above is a concise summary of our check list and shows how this American Optical plant was rated. We think the plant able to score "outstanding" in all categories is rare indeed but we hope to report on others as we learn of them.

amid the quiet and natural beauty of the setting of A-O's award winning plant, tunnel carries services to the huge lens plant over the Quinnebaug River

Plant Award of Merit

By A. W. HINDENLANG,

Assoc. Editor

Photographs by

T. GAWLICKI

Fig. 1 COMBUSTION Editor and Publisher J. C. McCabe presents Award of Merit to (left to right) B. W. Devine, E. V. Lewis and Harding B. Jenkins (A-O Photo by Irene Daviau)

WE FOUND the headquarters of American Optical Co. on the banks of the Quinnebaug River in the quietly charming, tree-shaded Massachusetts city of Southbridge. So friendly and courteous are the city's 17,000 people that no traffic lights are needed on the bustling 8-lane-wide main street. Southbridge, the center of America's lens industry, offers a striking contrast in the new and the old. While A-O's research is as modern as the day after tomorrow, nearby Old Sturbridge Village is a page of history straight from the days of the first New England colonies. The cathedral of Notre Dame ranks with the finest in the world. Its memorial plaques and beautiful stained glass windows are inscribed in French—testimony to the predominantly Gallic background of the townspeople.

American Optical's power plant at Southbridge, Mass., is carrying on today a tradition of service that began 127 years ago—it was back in 1883 that jeweler William Beecher began making frames for spectacles, starting the business that the world knows today as the American Optical Co.

Services

The story of A-O's first power plant on the banks of the Quinnebaug would be an interesting article in itself but history has regrettably left us very few details of its operation. Its modern counterpart, however, is a model industrial power plant—a refreshing find in an age where too many industrial plants are considered by management as necessary evils.

This plant furnishes all required services to 1,250,000 sq ft of manufacturing, office and research facilities in 47 buildings. The buildings are spread out over 113 acres on both banks of the river and service lines cross the river in above-ground tunnels like those shown in Fig. 2 Services supplied include:

Power and Light	2,000,000 kw/month
Heating and Process Steam	26,000,000 lb/month
Service Water	50,000,000 gal/month
Process Water	24,500,000 gal/month
Compressed Air	53,000,000 cu ft/month

Major equipment items used to provide these services are:

4 Turbo Generators, 1 Hydro-Generator

(1) double extraction, condensing turbine, rated 5000 kw at 2400 v, extraction at 50 psi and 3 psi (Fig. 3)

(1) single extraction condensing turbine rated 3000 kw at 2400 v, extraction at 3 psi

(1) single extraction, rigid base condensing machine rated 1250 kw at 600 v, extraction at 3 psi

(1) straight condensing, rigid frame machine rated 1000 kw at 600 v

(1) hydro-generator rated 200 kw at 600 v

Fig. 2—View through service tunnel looking across the river toward the power plant

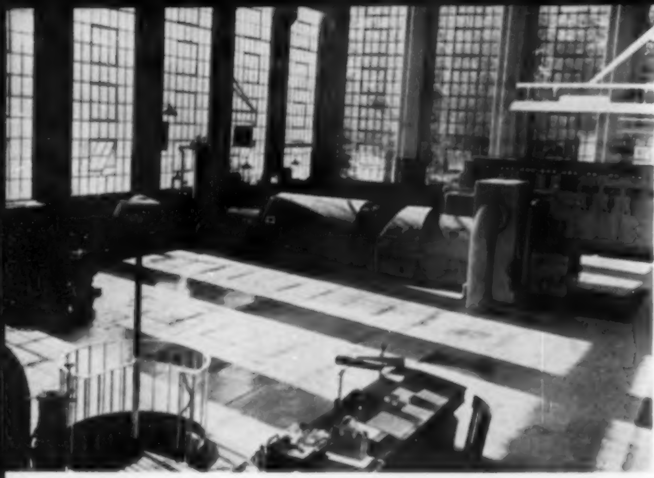


Fig. 3—View of turbine room showing 5000-kw Westinghouse turbine and 2400-v panel in background. Circular stairways, like the one in the foreground, may be unbolted and lifted out for passage of pipe or equipment

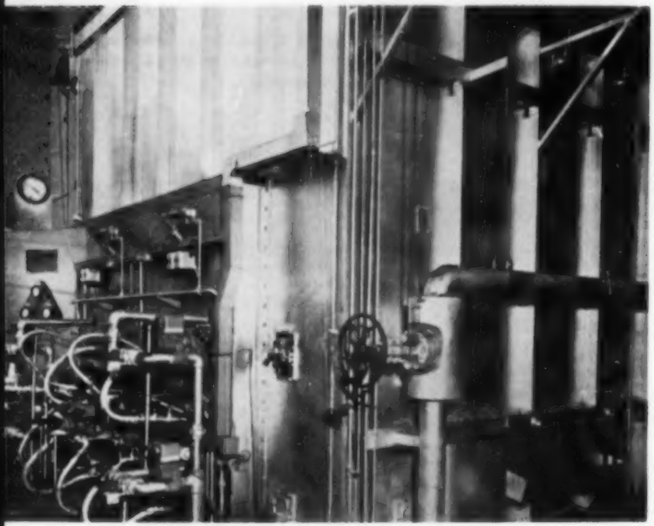
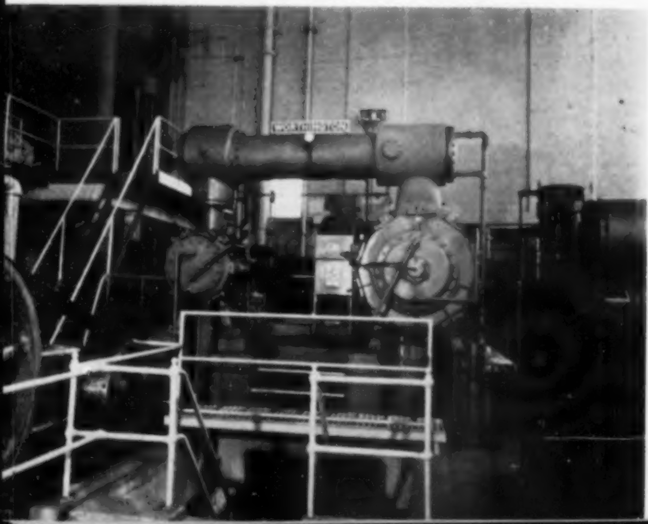


Fig. 4—125,000-lb-per-hr workhorse of the boiler team. A C-E VU boiler, this unit generates steam at 265 psig, 560 F. Firing floor at burner level makes height seem abbreviated

Fig. 5—View of A-O's compressor room showing part of the controversial foundation for the 500-hp, 3600-cfm horizontal compressor. Deaerator gallery is at the upper left



The 5000 kw machine does most of the work. The other three steam turbine generators are older and are used for peaking and back-up. The hydro machine is used whenever river conditions permit. Normal maximum demand is 5300 kw/hr with highest recorded peak at 5770 kw.

3 Steam Generators
(1) B&W rated 60,000 lb/hr at 260 psig, 560 F, erected 1932, oil fired
(2) C-E Walsh rated 100,000 lb/hr at 260 psig and 560 F, erected 1940, oil fired
(3) C-E VU rated 125,000 lb/hr at 260 psig, 560 F, erected 1948, oil and gas fired

As with the turbines the largest unit is the workhorse. Multiple fuel firing combined with a favorable interruptible gas rate means real fuel-dollar savings. (See Fig. 4.)

5 Air Compressors (all operate at 87 psig)
(1) 500 hp horizontal rated 2600 cfm
(1) 200 hp horizontal rated 1000 cfm
(1) 150 hp "Y" rated 800 cfm
(1) 175 hp angle compound rated 800 cfm
(1) 75 hp angle compound rated 450 cfm

A partial view of the scrupulously clean compressor room is shown in Fig. 5.

Unfortunately space does not permit listing all the items of plant equipment. Other individual units are described elsewhere in the article.

Naturally some service demands vary seasonally, others fluctuate with manufacturing hours—but always the supply is available, reliable and efficient.

Efficiency

What are the secrets of operating an efficient industrial power plant? Ted Lewis, Plant Engineer, and B. W. Devine, Chief Engineer, Power Plant, offer this formula:

(1) Know the precise cost of product (kilowatts, pounds of heating and process steam, gallons of process water, cubic feet of air, etc.).

(2) Use an accurate budget that includes *all* costs and is corrected monthly to reflect fluctuating fuel costs.

(3) Set up a system to continually check quality of product, raw materials (fuel and water) and performance of equipment.

(4) Use these records to determine where investment should be made to increase efficiency and how it can be justified.

(5) Set up a maintenance program to: (*a*) Keep equipment operating at top efficiency through planned preventive maintenance; (*b*) indicate by simple maintenance cost records the point where new equipment is justified.

Later on in this article we'll discuss the simplicity and effectiveness of the record system required to carry out this formula for an efficient plant operation. Let it be enough for now to say that the system works—and works very well. For instance Fig. 6 shows Messrs. Lewis and Devine checking their year-old oxygen meter (a device found in too few industrial plants). Scanning his performance records Devine noted a failure to maintain proper excess air with continually changing firing rates and fuels. High excess air was naturally causing a waste of fuel dollars—and it showed clearly in the records.

Devine and Lewis were also attracted by the safety factor represented by an oxygen meter (safety means reliability and hence lessens the probability of heavy outage expenses). To make the story shorter the meter was installed and paid for itself in less than a year. Boiler operators are now able to maintain optimum excess air at all loads and firing conditions. This has meant improved evaporation from 14-plus pounds of steam per pound of fuel to 15-plus pounds per pound—a fine achievement in any plant.

This evaporation rate corresponds to a boiler efficiency of 87 per cent. The C-E unit carrying most of the load manages this efficiency without an air heater. An economizer is used, however, and is the basis for another short story on justification of investment.

Temperature of flue gas leaving the boiler is as low as 320 F. Water temperature at economizer inlet was 225 F and sulfur content of fuel oil ran as high as 4 per cent. These conditions in combination meant that an economizer would last only 18 months before complete replacement was required. Replacement cost $25,000 including labor. Since the economizer means 7 per cent in boiler efficiency something had to be done to extend the life of economizer surface. A-O's Devine and Lewis put their heads together with C-E's Doc Mumford and others to seek a solution. Upshot of the meeting was the decision that corrosion was primarily a function of tube metal temperature. Indicated solution was to install a closed F. W. heater to raise water temperature at economizer inlet to 280 F. Installed cost of the feedwater heater figured to be $10,000 against a predicted economizer life of ten years. Since economizer renewals were costing $16,000 annually the proposed heater seemed a wise investment. The heater was installed in December 1957 and has been in continuous service ever since. Checks during annual inspections have shown no measurable corrosion and the original prediction of economizer life has been extended from ten years to "indefinite."

Prudent shopping now permits A-O to purchase oil with a sulfur content not much above 2 per cent at no price premium and regular analyses in the power plant lab insure that deliveries stay in this low sulfur range.

Fig. 8 offers dramatic evidence of what can be accomplished by keeping good costs records and applying them. Note that the cost/kw curve shows no improvement from 1954 to 1956 and even a slight rise in the 1956–1957 period. Actual operating dollars per year climbed alarmingly during the same period. Clearly, the records showed, it was time for action if such action could be economically justified. Because of some foresighted planning something could be done. The newest 5000 kw turbine generator had been purchased for 3 psi extraction with future extraction at both 50 psi and 3 psi. The cost of piping up for 50 psi extraction and converting building heating for high pressure service was estimated at $50,000. Cost analysis (based on excellent records) indicated that the installation would pay for itself in a little less than one year. The remarkable drop in cost/kw and dollars per year attest to the effectiveness of the 50 psi extraction installation.

Faced with a kilowatt cost as low as 10.5 mills and with a budget that gets tighter as efficiency is improved it is hard to see how the A-O power plant team can squeeze much more squeal from the hog—but we certainly won't bet against their improving still further.

Fig. 6—A-O's award-winning team—E. V. Lewis, left, and B. W. Devine, right, check oxygen recorder

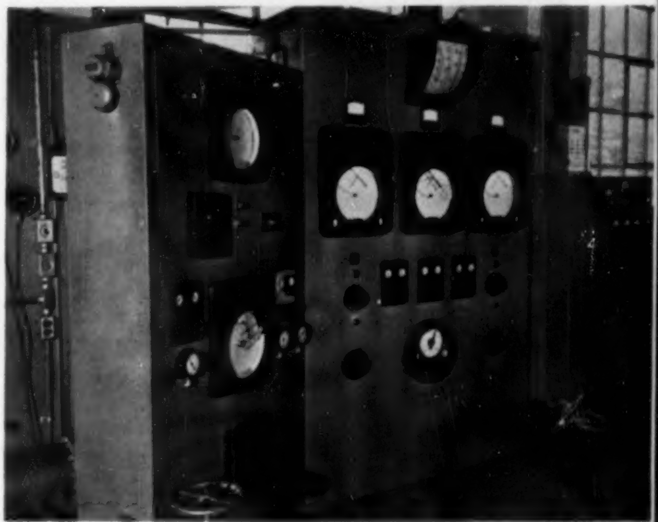
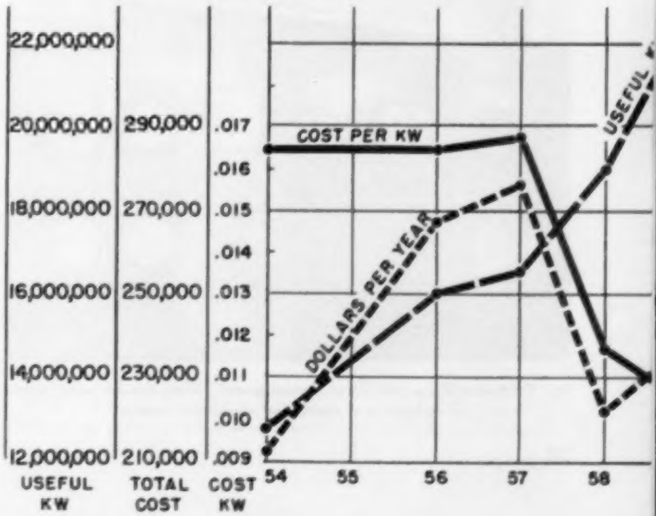


Fig. 7—Instrument and control panel for the principal boiler. Small panel at right holds flame safeguard controls. Wires beneath it are for tests described in article to appear in Feb. COMBUSTION

Fig. 8—Curves show load growth, dollars per year for power plant operation and cost per kw generated. Note remarkable drop in kw cost and total dollars wrought by 50 psi extraction installation in 1957



Housekeeping and Maintenance Outstanding

It is practically axiomatic that a good looking power plant is a well run plant. And it follows that such a plant has first rate maintenance policies and practices.

The photographs accompanying this article speak for themselves in attesting to the outstanding housekeeping at this A-O plant. We think it only fair to point out that no special preparations were made for these photographs. They represent the plant just as it appears day in and day out. An unusual feature about this type of housekeeping is that there aren't any extra hands around who have little else to do but "polish brass."

One man in the firing aisle and one man in the generator room run the plant. Messrs. Gillespie, Thibodeau, Leighton and McGovern man the generator room while Navis, Zuiss, Kazmarek and Bastardo are responsible for operating the boilers and auxiliaries. Morale is high and competition for top performance between the various shifts is intense. Here again well-kept records help by showing the performance of each shift.

Ed Nelson heads up the maintenance crew which is made up by Messrs. Rheaume, Lippe and Sekula. This crew is exceptionally well equipped and capable of almost any in-plant repair job. That the crew is on its toes is proved by the fact that the only thing we found leaking in this plant was information—and it was given freely and with obvious pride.

Maintenance is regularly scheduled on all equipment and it pays off in direct dollars and reliability. Wash water, for instance, is vital to lens processing. Each week end one of the three wash water pumps is checked thoroughly so that each pump gets a good going over and repair as needed at least every three weeks. This type of planning takes much of the urgency out of emergency maintenance. The wash water control panel (Fig. 9) offers a good illustration of maintenance planning. This Hungerford-Terry panel maintains constant pH for flocculation, introduces the correct amount of alum, automatically desludges the settling basin, automatically corrects pH of finished effluent and controls flow of inlet water to filter and mixing chamber and flow of effluent. It further indicates and records the operation of the entire process. The panel is a complex of electric and electronic instrumentation but a special rack behind it holds all the spare fuses, tubes, relays and other components that might be required for emergency repair. This kind of planning ahead saves process down-time, confusion and dollars.

Fig. 9—Automatic wash water control panel. Rack behind panel holds complete set of spares for emergency repairs

Another feature of the housekeeping-maintenance program at A-O is the card record for each item of equipment down to unit heaters and bubblers. Each repair and its cost is logged on the maintenance card. A card with numerous or especially costly entries immediately suggests that new equipment may be called for. And it gives a sound basis for justifying the expenditure. Comments on how records have contributed to plant efficiency and good maintenance lead naturally to some discussion on the records themselves.

Plant Records

A tax form provided the inspiration for the Power House Daily Steam Distribution sheet shown as Table I. Starting with total steam generated this sheet progresses to "gross steam to electrical distribution." The next heading "turbine credits" accounts for all the heat taken from the turbine (50 psi extraction, 3 psi extraction, condenser cooling water to heat wash water, etc.). The constants used on each line convert this extracted heat back to boiler conditions. The next step quite logically is to subtract total "turbine credits" from "gross steam to electric generation" thus arriving at "net steam to electric generation." Breaking the sheet down to word and number equations we find the following:

(1) Steam Generation.......................1,992,000

(2) Gross Steam to Elec. Gener.	−	Turbine Credits	=	Net Steam to Elec. Gener.
1,874,400 (line 23)	−	1,359,603 (line 47)	=	514,797 (line 48)

At this point we see that:

$$\frac{\text{Net Steam to Elec. Gen.}}{\text{Kw Generated}} = \text{Heat Rate for the Day}$$

or

$$\frac{514{,}797 \text{ lb}}{85{,}500 \text{ kw-hr}} = 6.02 \text{ lb/kwhr}$$

(3) Steam to Power House...................305,394 (line 68)

(4) Gross Bldg. Ht. and Process Stm.	−	Bldg. Ht. and Process Credits	=	Net Stm. to Bldg. Ht. and Process
or				
993,047 (line 77)	−	70,583 (line 88)	=	922,464 (line 89)
(5) Stm. to Wash Water	−	Condensate Credit	=	Net Steam to Wash Water
or				
266,172 (line 94)	−	16,608 (line 96)	=	249,564 (line 97)

Totaling up the distribution we find a discrepancy:

Steam Generation (line 13)..................1,992,000

Distribution:

Net to electric (line 48)..........514,797
Net to power house (line 68).....335,394
Net to bldg. htg., etc. (line 89)..922,464

Table I—Power Plant Daily Steam Distribution

Steam Generation				
1		Stop		
2.	No. 1	Start		
3.	Boiler	Diff.	× 1350	1,922,000
4.		Stop		
5.	No. 3	Start		
6.	Boiler	Diff	×	
7.		Stop		
8.	No. 4	Start		
9.	Boiler	Diff.	× 900	
10.			TOTAL	1,922,000
Gross Steam to Electric Generation				
11.		Stop 3062		
12.	5000	Start 1500		
13.	Turbine	Diff. 1562	× 1200	1,874,400
14.		Stop		
15.	3000	Start		
16.	Turbine	Diff.	× 750	
	1250	Total KW Hr		
17.	Turbine		× 39.69	
	1250	Total Hr		
18.	Vac. Pump		× 378.52	
	1000	Total KW Hr		
19.	Turbine		× 33.08	
	1000 Vac.	Total Hr		
20.	Pump		× 378.52	
21.	Exciter	Volts × Amp	× 1276	
22.	C. W. Pump	Total Hr	× 1700	
23.			TOTAL	1,874,400
Turbine Credits				
24.	5000	Stop 4957		
25.	50#	Start 3545		
26.	Extraction	Diff. 1412	× 454	641,048
27.		Stop 70841500	63-32=31	
28.	5000	Start 70311000	$\times \frac{T-32}{1300}$	
29.	Condensate	Diff. 530500		12,650
	5000 3#	Line 13 − Lines		
30.	Extraction	26, 29 Diff.	× .831	584,070
31.	5000	Stop 81565	51-33=18	
32.	Wash	Start 67854		
33.	Water	Diff. 13711	× .48 (T−PT)	118463
34.	3000	Stop		
35.	Wash	Start		
36.	Water	Diff.	× 48 (T−PT)	
37.		Stop		
38.	3000	Start	$\times \frac{T-32}{1300}$	
39.	Condensate	Diff.		
	3000 3#	Line 16		
40	Extraction	− Line 39 Diff.	× .831	
	1000			
41.	Condensate	Line 19	$\times \frac{T-32}{1300}$	
	1250			
42.	Vac. Pump	Line 18	× .8794	
	1000			
43.	Vac. Pump	Line 20	× .8794	
	Elliot			
44.	Exciter	Line 21	× .8794	
45.	C. W. Pump	Line 22	× .8794	
46.	Make-Up	F. W. Lb × DT	÷ 1300	3372
47.			TOTAL	1,359,603
Net Steam to Electrical Generation		85,500 kw, 6.02 lb per kwhr		
48.	Net Steam	Line 23 − Line 47	TOTAL	514,797
Boiler Feed Water				
49.		Stop		
50.	No. 1	Start		
51.	Boiler	Diff.	× 1450	2,017,000
	No. 3			
52.	Boiler	Line 6	× 1.025	

53.		Stop		
54.	No. 4	Start		
55.	Boiler	Diff.	× 1450	
56.			TOTAL	2,017,000
Steam to the Power House			5000 condsate	12,650
57.	Steam to	Stop 7549		
58.	Fuel	Start 7438		
59.	Oil	Diff. 111	× 378	41,958
	Closed	F. W. Lb (dt)	266-223=43	
60.	F. W. Heater	2,017,000	× .000996	86,384
	Open	F. W. Lb (dt)	105-32=73	
61.	F. W. Heater	2,017,000	× .0005	73,620
	Bldg. H. & P.			
62.	Condensate	Line 88		70,583
	G. E. Feed	F. W. Lb Pumped		
63.	Water Pump		× .00586	
	Wash Water			
64.	Condensate	Line 96		16,608
65.	Feed	Stop 5567	48-32=16	
66.	Water	Start 0891		
67.	Make-Up	Diff. 4676	× .048 (dt)	3,591
68.	F. W. Lb		TOTAL	305,394
Gross Building Heat & Process Steam				
69.	All Red. Steam	Line 10 − Lines 23, 59, 63, 76		75,642
70.	50# Ext. Steam	Line 26 − Line 60		554,664
71.	3# Ext. Steam	Lines 30, 40 − Lines 61, 92		362,741
	1250			
72.	Vac. Pump	Line 42		
	1000			
73.	Vac. Pump	Line 43		
74.	Exciter	Line 44		
75.	C. W. Pump	Line 45		
	G.E. Feed			
76.	Water Pump	Line 63	× 7.29	
77.			TOTAL	993,047
Building Heat & Process Credits				
78.	Total F. W.	Line 56		2,017,000
	W. Water			
79.	Condensate	Line 95	239,888	
	5000			
80.	Condensate	Line 29 Diff.	530,500	
	3000			
81.	Condensate	Line 39 Diff.		
	1000			
82.	Condensate	Line 19		
	Closed			
83.	F.W. Heater	Line 60	86,384	
	H. Water	Hr (dt)		
84.	Heat'g System	× 352.55	203,069	
	F. Water	Line 67 Diff.		
85.	Make-Up	× 62.5	292,250	
86.			TOTAL	1,352,091
87.	Condensate	Line 78 − Line 86		664,909
88.	Net Credit	Line 87 (dt)	÷ 1300	70,583
89.	Net Steam	Line 77 − Line 88		922,464
Steam to Wash Water				
90.		Stop 81,565		
91.	Wash	Start 67,854		
92.	Water	Diff. 13,711	× .399 (dt)	147,709
93.	Con. Credit	Lines 33 plus 36		118,463
94.	Gross Steam	Lines 92 plus 93		266,172
95.	Condensate	Line 92 Diff.	× .648 (dt)	239,888
	Cond.			
96.	Credit	Line 95	$\times \frac{T-32}{1300}$	16,608
97.	Net Steam	Line 94 − Line 96		249,564

Net to wash water (line 97).....249,564

Total Distribution.....................1,992,219

We see that total distribution is 219 lb over measured steam generation. In this particular sample day, selected at random, this closing error amounts to only one hundreth of one per cent and lines 68, 89 and 97 are simply reduced to make the totals agree. We are told that this closing error seldom gets as high as one quarter of one per cent.

Obviously with this kind of information it becomes a simple matter to assess cost of product to the proper departments and to determine precisely the cost of making product.

Information required to make proper entries is obtained from planimeter measurements of flow chart areas for the following:

(1) Boiler Steam Flow
(2) Gas Flow
(3) Steam Flow to Turbine
(4) Heating System Steam Flow
(5) 50 Psi Extraction Flow
(6) Steam Flow to Condition Fuel Oil, including:
 (*a*) atomizing steam
 (*b*) fuel oil service heaters
 (*c*) storage heating
 (*d*) day tank heating
 (*e*) oil pumping

(It is interesting to note that total steam for fuel oil conditioning and burning averages 1.6 per cent of total generation with a peak near 2.0 per cent in the coldest month. The Lewis-Devine team has plans afoot for a higher pressure pump set and burner tips of improved design to reduce atomizing and overall steam consumption still further.)

A log sheet like Table I is filled out daily and evaporation rate and boiler efficiency are noted on the reverse side. For the date shown evaporation was 15.2 lb steam per lb of fuel and boiler efficiency was 87.0 per cent.

A condensed weekly form verifies the trend of the daily work sheets and monthly results go into the budget sheets.

Budget System

Mr. E. V. Lewis describes his budget or comparative cost system this way:

"Under the previous system, a yearly budget was set up to run the Power House. This was broken down into amounts according to accounting periods. It did not take into account such variables as the fact that it costs more in the Winter to heat buildings than it does in the Summer, the variations in the price of fuel or the seasonal demand for power and other services, such as water and air, normally furnished by the central station. It was impossible under this system to obtain costs for units of services except on an annual basis, and by the time the figures were at hand, it was too late to do anything about them.

"We set out to devise a system of cost accunting that would give us monthly checks on unit costs, and a method of comparing actual costs with budget allowances for units of services by months.

"Since the main variable and largest single expense of any Power House is fuel, our first step was to separate this from the total. All remaining costs, including maintenance, operating expenses, and overhead, are lumped into what we call standby.

"Fuel costs were arrived at by the following method. previous Power House cost records were complete enough so that we could arrive at total yearly fuel costs for each service, and since the variable was either heat or power, both covered by records, we simply divided this cost by the total units produced to obtain a unit fuel cost for each type of service—even to the point of being able to separate the heat from the power. By averaging these unit costs for each of the services over a three-year period, we were able to set standard history fuel cost figures.

"In order to present a true picture as to the comparison between the budget and actual, we did two things: (1) to start off, we used the averaged actual price of oil of the past three years and said that this would be the price of oil for the next year. This was used as a standard fuel cost. Fluctuations in the price of fuel were reflected in the budget by changing the standard history costs to correspond percentage-wise to the actual fuel cost. For example, if the standard fuel cost was \$.0700 and the actual cost of fuel during the same period was \$.0600, then all of the standard history costs would be reduced by 14.3% for budget purposes. (2) actual units of services used during the budget period are now multiplied by the adjusted standard history costs or price to arrive at a figure for budget purposes. This gives a flexible budget that follows both a fluctuating fuel price and a fluctuating use.

"The budget standby was simply broken down into the unit costs from actual records.

"For the actual budget for comparison purposes, we use the following procedure: divide the total actual cost of fuel by the total steam produced for a cost per pound of steam. The total steam is broken down into the amounts used for each of the various serivces. These figures, times the cost per pound, give the total fuel cost for steam for the period for each service. Since some of the energy supplied to the various services is in the form of power, the electrical cost is further broken down by prorating the electrical costs according to the amount used. These figures added to the steam costs above give us the breakdown of the fuel costs by services.

"The actual standby is allocated to the various services by using the same percentages as is used in the make-up of the budgeted standby.

"We now have equitable figures for comparison purposes that are fairly accurate for any reasonable condition.

"Actual unit prices are now obtained by dividing the total costs by the units produced.

Table II shows a typical monthly cost sheet showing Budget, Actual and Standard cost figures. Note that at the bottom of the right hand column standard fuel cost is compared with fuel cost for June 1960 to arrive at a *per cent of actual* fuel cost. This ratio (0.80713) is applied to each of the fuel cost figures in the Standards column—thus (0.009020) $\times$ (0.80713) = (0.007280) for total dist. kw and fuel. This effectively brings the Standard cost into the focus of today's fuel cost.

Similarly at the bottom of the left hand column the Budget fuel figure and the actual fuel figure for June are used to obtain a ratio (0.89267) which is used to bring

TABLE II AMERICAN OPTICAL COMPANY—COMPARATIVE POWER HOUSE COST—PERIOD ENDING: 7-1-60

1960 Distributed Production	I Cost	II Budget Units	III Price	IV Cost	V Actual Units	VI Price	VII Cost	VIII 1960 Units	IX 1958 Standard Price
Electrical				24,431	2,107,450	.011830			
Main Factory					579,370				
Lens Factory					924,400				
Case Factory					25,950				
Bldg. #17 Lab.					28,780				
Bldg. #19 Glass Lab.					16,800				
Bldg. #48 Glass Mfg.			.005737		289,800				.007280
Total Dist. KW & Fuel $	10,700		~~.006427~~	12,563	1,865,100	.006736	13,578		~~.009020~~
Standby Cost	11,624			10,735			10,735		
Total Cost	22,324		.001969	23,298		.012492	24,313		.013036
Air			.000019						.000017
Dist. Cu Ft & Fuel $	1,003		~~.000021~~	938	52790534	.000018	897		~~.000021~~
Standby Cost	1,962			1812			1812		
Total Cost	2,965		.000056	2,750		.000052	2709		.000051
Wash Water			.000010						.000015
Pur. & Dist. Gals. & Fuel $	245		~~.000011~~	326	24466175	.000013	367		~~.000018~~
Heated lbs. & Oil $	859		~~.000707~~	731	1,360717	.000537	894		~~.000814~~
Total Oil cost	1104		.000631	1057			1261		.000657
Standby Cost	4048			3739			3739		
Total Gal. & Cost	5152		.000211	4796		.000196	5000		.000204
Service Water			.000011						.000008
Dist. Gals. & Oil $	552		~~.000012~~	369	50216,100	.000007	402		~~.000010~~
Standby Cost	1332			1230			1230		
Total Cost	1884		.000038	1599		.000032	1632		.000032
Steam—Industrial—Heat'g									
Bldg. Heat			.000642						.000661
Total Dist. Lb & Oil $	5820		~~.000719~~	4872	8,064756	.000537	5992		~~.000819~~
Standby Cost	5578			5152			5152		
Total Cost	11,398		.001257	10,024		.001106	11,144		.001229
GRAND TOTAL									
Oil Cost Std. .07143	19,179			19,799			22,130	Std.	.079
Standby Cost Act. .0637635	24,544			22,668			22,668	Act.	.0637635
Total Cost *% of Act. .89267	43,723			42,467		.9236	44,798	% Act.	.80713

the budget fuel cost for each service right up to the minute. (For example—Total dist. kw and fuel has a unit fuel Budget figure of 0.006427. Correcting, this becomes (0.006427) × (0.89267) = 0.005737. Then multiplying the fuel rate (0.005737) by useful kw distributed (1,865,100) a Budget fuel figure of $10,700 is obtained. This, added to the standby budget item of $11,624 gives a total corrected Budget figure of $22,324, or a total unit cost of $0.011969/kw. The budget total compared to actual costs for the month (col. IV) shows performance running slightly over the budget for June. (Editor's Note: Readers should note that this is not bad at all for a vacation month during the summer when plant efficiency drops off. The grand total shows the plant over-all is within the corrected budget.)

Comparing column VII with columns I and IV shows that the plant is consistently bettering its average performance for the past three years as represented by the corrected standard cost. The only exception is a slight discrepancy in total cost of compressed air distribution between actual cost (col. IV) and standard cost (col. VII). This is probably accounted for by the added overhead of the new 500 hp compressor which did not figure into the standard (prior three years) cost. It does show in a higher budget standby cost, however, so that the plant is again operating below its monthly budget.

The beauty of this type of chart is that it presents a clear picture of what is happening in the important realm of costs in every department of service. It shows this picture in a reference frame that is as up-to-the-minute as it can possibly be made. Each month management can check its operation against a monthly budget figure reflecting actual fuel costs for the month and against a figure for the past three years, again corrected to show the effect of actual current costs. Corollary advantages such as having accurate unit costs for services and early determination of trends are obvious and important.

One of the harassing aspects of record keeping is the time and effort that goes into logging the information and keeping it accurate. Once again American Optical seems to have achieved an excellent solution. Power plant records are the province of Miss Mary Mack who receives all the charts and log sheets from the operators, planimeters the charts, makes the entries in the distribution chart (Table I), runs the calculations and figures daily and weekly evaporation and efficiency. Working in the Chief Engineer's office in the plant, Miss Mack is in very close contact with operation and can spot a logging error with a practiced eye. Her counterpart, Miss Paula Veshia, while acting as secretary to Plant

Engineer, Ted Lewis, finds time to keep the budget records. These girls have a remarkable grasp of the overall operation and its details—in fact it was they who explained the system to us.

Ingenious Solutions

Neil Clark in the Satevepost claims that this country has about all the experts it can use but worries about the serious shortage of *inperts*. "An inpert, unlike an expert, hasn't been tamed and trained and taught how it must be done."

A-O's Devine and Lewis seem to us to be very definitely in the *inpert* category in rising to unusual and ingenious solutions to knotty problems. This ability we think is a prime indicator to outstanding plant operation. Almost any problem can be solved by conventional methods if enough dollars are available but the man who rates our kudos is able to meet the challenge of the unusually difficult with an unusually ingenious approach that saves dollars.

For instance in Fig. 5 you'll see the new 500 hp air compressor located just behind the stairway leading down to the pump room. Obviously this compressor is not resting on a conventional foundation. There simply was no place else to put this machine without considerable added expense. Thereupon the Devine-Lewis axis designed a modified cantilever foundation using reinforced concrete posts and lally columns arranged to clear equipment and major piping below the operating floor. The compressor manufacturer rejected the foundation design, of course, but work proceeded without approval—it had to. Anchor bolt arrangement was so precise the compressor erector claimed it was the first time he'd seen a machine slip into place so neatly. The machine started up without incident and when manufacturers representatives came to inspect it they were greeted by the sight of dozens of coins perched *on edge* all over the foundation and compressor. One in fact stood on edge on the cylinder, normal to the direction of piston travel. While the manufacturer still doesn't approve this type foundation he cannot fault the continued smooth operation wrought by its unique design.

Then there was the time the river nearly ran dry. Cooling water requirements during summer months run about 11,000 gpm. During severe dry spells, Bernie Devine had figured, the river might not be able to supply required cooling water. The obvious answer of course was to build a cooling tower for full protection during the summer. During the summer of 1957 the level of the Quinnebaug was rapidly dropping to the danger point. Mr. Devine had thoughtfully provided himself with 20 spray nozzles some time in advance of the emergency.

Within a few weeks Devine and Lewis had designed, secured management approval and installed a complete spray pond system. Using two retired circulating water pumps rated 4000 gpm each against a 30 ft head at 40 hp they installed a tapered line designed to impose equal pressure head on each of the 4-in. spray nozzles. Of the 11,000 gpm circulating water requirement, 8000 gpm was returned to the river via the spray pond. Water temperature was reduced 10 deg F by the spray to within 1 deg of original river temperature. Very shortly after the installation was complete the system was badly needed. The longest previous recorded drought was 100 days. In the summer of '57 the spray system was run continuously for 99 days. Pumping costs are only about \$0.80/hr—and the entire installation including spray nozzles cost only \$3500. Fig. 10 shows the spray nozzles in operation.

Another example of Devine's *inpert* thinking will be featured in February COMBUSTION. This is the story of the solution of a problem that has vexed a number of us for years. The story of yet another ingenious approach cannot be told at this writing but will be forthcoming in an early issue. This type of thinking we submit can come only from a power plant team who are deeply interested in their work and who are good enough at it so that a departure from convention holds no fears for them.

Performance Checks

When you've become proficient at an art whose methods are constantly improving through change, the only way to stay proficient is to continuously check your performance. This checking is a creed at American Optical and it obviously pays off. One of the most outstanding features of A-O's check system is found in the combined Chief's office and laboratory shown in Fig. 11. Chief Devine's desk is just out of sight in the foreground. The rest of the lab-office is the domain of Miss Mary Mack, a highly competent technician who presides over the test equipment in addition to keeping the records mentioned earlier. From left to right around the room are:

(1) Fisher constant temperature (adjustable) oven
(2) Desiccator
(3) Phipps and Bird Jar Tester—used to determine required alum or floc agent to remove suspended solids from wash water and boiler water
(4) Cabinet containing O_2 cylinder and valving for feeding O_2 into bomb calorimeter at 300 psi
(5) Emerson Adiabatic Jacketed Bomb Calorimeter with thermometer calibrated in hundredths of a degree C (just to the left of the calorimeter is a special bomb firing panel with lights and switches—designed and built by A-O)
(6) Chain-o-matic balance with Bureau of Standards calibrated weights. Accuracy of this scale is one tenth of a milligram (about 0.0000035 ounce)

Not shown are a conventional Orsat gas analyzer and a Taylor comparator used to check chlorination of service water, condenser shot feeding and occasionally wash or process water.

At the present time boiler feedwater is checked in a small separate laboratory on a gallery above the turbine floor. Maintenance group leader Ed Nelson and Jerry Lippe perform all the conventional checks there. Present plans call for moving the feedwater test equipment to the main lab in the near future.

What is accomplished by laboratory checking? For one thing A-O is assured that it gets full value for its fuel dollar. The bomb calorimeter tells the story on whether the heat content purchased was actually delivered. The investment in equipment is protected by insuring that the supplier keeps the sulfur content of fuel oil down where it is supposed to be by purchase specification.

The test equipment also saves dollars on chemicals used for conditioning water. For instance the conventional method of testing a water sample, getting a

Fig. 10—View of power plant with cooling water spray system in operation. Note uniformity of spray controlled only by reducing pipe size

Fig. 11—Combined Chief Engineer's office and power plant laboratory. Equipment is described on opposite page

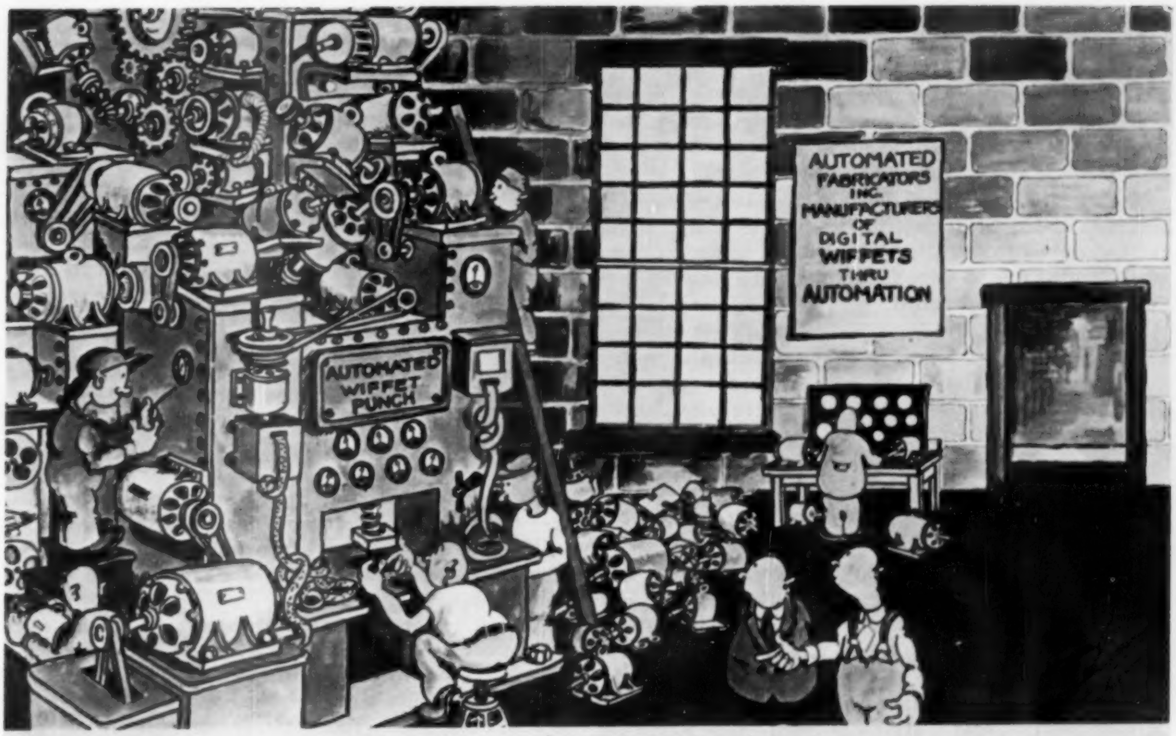
prescription and then treating in accordance with prescription meant that A-O was adding 32–50 ppm alum to flocculate wash water. When the jar tester was added to the lab it was found that 16 ppm was the optimum figure and resulted in no residual alum in the wash water. Treating costs were cut in half and the improved quality of the effluent contributed to process improvement.

The lab equipment has proved invaluable in emergencies. On two occasions industrial accidents upstream raised the pH of the river water to 10.5 in one instance and lowered it to 4.2 in another. Naturally both cases caused serious plant upsets but immediate analysis showed what was wrong and how to correct it. It is not inconceivable that either of these accidents could have caused complete plant shutdown had not the trouble been detected and remedied at once.

Despite all these advantages accruing from proper testing equipment we know of few industrial power plants that are similarly equipped. The tragic aspect of this situation is that, while expense is the reason usually given for not installing test equipment, A-O's equipment and furniture investment is estimated at only $2500–$3000. It is a wonder to us how most plants can afford to do without. (Editor's Note: Because of the direct efficiency return and added safety the oxygen meter is here considered an operating instrument rather than test equipment and is not included in this estimate.)

Morale

When we encounter performance like that described here we can usually credit the factors already discussed—equipment, records, checks on performance and the like. But we feel that these could never do the job without the one great intangible that makes the plant really effective—morale. This is an abstract term that is difficult to define but when you're in a plant where morale is high you know it instantly. You feel it in a dozen ways—spotless appearance of plant and equipment, the ready smile, pride in describing operation, pride of performance, the lack of wasted effort, the air of quiet confidence—these and more. It starts at the top with the interest of management and the dedication of Ted Lewis and Bernie Devine and spreads through the entire power plant staff. They run a tight ship and they're proud of it—and so are we.



"This Proves That Automation Doesn't Cause Unemployment"

Courtesy of Industrial Products Group, Minneapolis-Honeywell Regulator Co.

Memories of the Good Old Days

By Lesie G. Smith

Chief Engineer, Port Jefferson Station, Long Island Lighting Co.

SINCE old-timers in this power station game often say "remember the good old days" let's reminisce a little.

Remember when a modern power station contained—a 200 psig boiler, a turbo-generator unit about 10 mw, a jet condenser, an open heater, and a steam-driven boiler feed-pump? Two years of grammar school to be a watch engineer—a high school diploma to be a chief. This is a far cry from the modern power station of today, with its huge turbo-generator units, high-pressure boilers, myriad auxiliaries, and its complicated automation.

In the good old days one only heard occasionally a stuck safety valve or a blown gasket, one operated by the drone. Today, things have changed and as the alarms come up and the windows light, it requires at least an understanding of English to diagnose one's trouble.

Remember back in '31? Time off in lieu of overtime, one-half day off on Christmas, the 54-hr week? Thirty bucks a week put a fellow in the upper income brackets. You left home at 5 a.m. to get to work at 7. What a grind! A bus ride, a walk, a train ride, then another walk. Now we complain if we have to park at the far end of the parking lot.

Did you ever handle one of those good old-fashioned coal-scoops? They just don't build them so wide any more. Then maybe things changed for you. You got a hand-operated drag-line scoop and spent more time on your hands and knees than on your feet. A good day's work was 20-tons of coal to the hopper. A far cry from the 400-tons per hour now handled by our modern bulldozers. You think you were underpaid? Let's face it, you really weren't producing much more than honest sweat.

As you progressed you no doubt operated one of those coal hoists, maybe a monorail rig—oh, those bumps. I often wondered if that hoisting drum was helping at all, or were we lifting that $1^1/_2$-ton bucket by sheer brute force on those hoisting levers—again, a far cry from our

automated modern towers, with their air-conditioned cabs; and to top it off, those leather upholstered chairs, moving and reclining at will.

I'm sure you remember those cool, cool jobs—maybe renewing a stoker tail-grate, a quick trip through that fire door with a cardboard to shield you from the radiant heat of that fire hoed-up against the front wall.

Remember the automation? The asbestos flappers precisely balanced to operate the outlet damper via pilot valve control. All you had to do to get on complete manual was to force those fires, warp your flappers—and boy, you had had it.

Remember the coal lorries—if you didn't get the darn things set just right you spent half your watch shoveling coal off the floor—and oh, those lunches in the fire-room! If coal-dust is injurious to health, then there just wouldn't be any old-timers to reminisce.

You may not believe it, but the best six-inch float-operated valve we ever had was operated by a five gallon paint pail weighted down with dry sand—ten years, no maintenance, and never a stuck valve.

And, oh yes, the good old Smoot-regulators. You know, the darn things were okay, but every operator carried a bunch of weights, one for every regulator and one for every load.

And oh those boilers! The most valuable mechanic was a good bricklayer. Remember counting the brick in your ash pile, and everyone guessing "now where did that one come from."—and the water-wall blocks, often thought there was asbestos in that block-paste, just to help burn the darn things out; and the old Calumet burners seemed they always closed up when things got rough; and your horror to find that the slag screen plug was not caused by a slag build-up, those darn superheater tubes just decided to get slag screen happy. Four weeks on the line was a record. Now we complain having to come off for the yearly insurance inspection.

No doubt you will forever remember your first turbine start-up. You rolled her smoothly to half speed—then all hell broke loose. She hit her critical—you hit your critical—she shook—you shook, the throttle shook—the gratings shook—but in two minutes you emerged the master; felt like a wet rag but you were filled with the pride of having brought her through.

And we talk about our modern quick-starts. Remember a boiler on the line in 50 minutes—and a ten minute turbine start? Oh well, these after all were emergencies. Never really knew how much our turbine would carry running atmosphere, until we burned all the cork off the condenser one night. It was a good thing that the condenser had those sliding tube ends with the ferrules and corset lacing—we really learned how little she'd carry.

And weren't those atmospheric valves cooperative—they just laid quiet-like with the turbine on the line while you took the covers off and cleaned out the muck. Were we ever lucky!

Remember the old chief insisting that you candle that 200 psig steam line for vacuum leaks—and how about lifting those weighted boiler doors and sitting half the watch lancing those tubes with air. How many free hair-cuts did we get—again no one seemed to get burned.

Oh yes, and those variable speed mill motors—how often have you barred them off dead-center? Didn't know for the longest time that the brush-ring was pitted. And who hasn't taken a rap at the duplex pump to get her going. *Those were the good old days*

And weren't we ingenious? A pail of asbestos, an extension light, and an air hose and one could operate any power station.

I remember dumping asbestos in a 20-in. atmospheric pipe each time the vacuum dropped. However, on a fine June day, fifty pails later, the turbine went high pressure, and we had the most spectacular June snowstorm and spent weeks cleaning roofs.

Another story I like to repeat relates to a turbine room fire. We had exhausted all of our fire extinguishers on the turbine elevation. We sent the fireman for our last remaining fire extinguisher located in the bunker area. Imagine our horror when the elevator door opened and he emerged from a cab full of foam, gasping and sputtering and looking like a husband on "People Are Funny."—Moral—Never invert a caustic fire extinguisher!

Then there's the story about the chief who installed his own wash room. Imagine his embarrassment when he flushed the thing—the mechanic had hooked the bowl to 125 psig saturated steam. Moral—be sure of your hook-ups.

And oh yes, weren't our heat rates good? Each chief carried a pocket full of leads for those coal scales and the short coal inventory each six months. Well you know, those lousy tugs were bunkering off your barge.

Well boys, there's much, much more, but for me, give me today and the modern power station. Each day a challenge—and don't those young squirts really keep you on your toes?

And now if I may, I'll end with a little verse, the writing of which, by the way, can be relaxing when things really get tough.

A Chief's Dream

Give unto me a station clean,
With trained personnel, I pray,
A plant that runs so smooth and well,
That I some golf may play.

A boiler that never puffs or slags,
A turbine, trouble free,
Auxiliaries that need no repair,
Oh! This is what I plea.

A quiet, patient, loving wife,
Who keeps my late meal hot,
A boss who really understands,
When all the safeties pop.

If all of these I cannot have,
I sincerely hope this day,
That this one wish, you'll grant me,
Before I pass away.

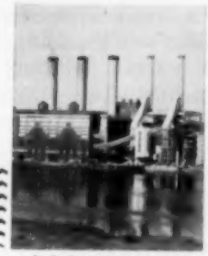
A stack so high, that eagles rest,
Upon its lofty brim,
That it may—SMOKE and SMOKE and SMOKE
And still the neighbors grin.

Oh well, what is life without a little humor—especially in this Operating Game?

Leslie G. Smith
Chief Engineer
Port Jefferson Power Station
(An Old Timer)

By A. L. H. GAMESON, H. HALL and W. S. PREDDY

Water Pollution Research Laboratory, Stevanage.



Part I of this article in December COMBUSTION discussed the increasingly important thermal pollution of rivers from the standpoint of temperature input conditions. This concluding installment discusses rate of exchange of heat, derives equations for heat transfer and considers application of the methods used.

Effects of Heated Discharges on the Temperature of the Thames Estuary—II*

Rate of Exchange of Heat

The heat continually entering the estuary is dispersed by tidal mixing and displaced toward the sea by the flow of land water. Part of this heat is eventually lost by displacement through the seaward boundary of the estuary (wherever this may be defined), and the rest escapes to the air and to the sides and bed of the estuary. Before it is possible to relate the observed distribution of temperature to the rate of addition of heat it is necessary to examine the movement of the water and the mechanism by which the excess heat is lost.

Tidal Mixing.—Water discharged to the estuary is not only displaced seaward by the entry of water upstream, but is also carried to and fro over an average distance of 8 or 9 miles by the tide and is dispersed by the mixing of the water that results mainly from tidal action.

The displacement by the fresh water flow is readily calculated from data for the flow and the cross-sectional area of the estuary. The average excursion of the water along the estuary due to the tide is likewise found from tidal levels and surface widths. The dispersion by mixing, however, is not calculable from existing data, neither can it be found from any practicable experimental work.

However, if the amount of cooling that takes place in the course of, say, three tidal cycles is not too great, then a knowledge of the distribution of the water after this period should be sufficient for the present purpose—even if the distribution after a single tidal cycle, or shorter period, is unknown. (It may be of interest at this point to anticipate the results found later, by mentioning that the proportion of the excess heat lost from the estuary by cooling in a period of three tides is of the order of one-fifth.)

The dispersal of water during one tidal cycle remains unknown; nevertheless it is possible to choose a form of representation which, although departing greatly from

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Numbers appearing in parentheses throughout the article refer to similar numbered References appearing at the end of the article.

the true distribution during one tide, is likely to be in substantial agreement with the true dispersion after a period of surprisingly few tides. Fig. 8 illustrates this point for three different symmetrical distributions, one of which is deliberately chosen to represent a very improbable distribution. In the case of an estuary like that of the Thames—which widens out progressively toward the sea—the mixing will be asymmetric: the quantity of water passing through a cross-section will be greater the nearer the cross-section is to the sea, and by considering the exchange of water across a boundary from the neighborhood of two sections equidistant from the boundary it is seen that a similar symmetric distribution at each section would lead to a net transfer of water across the boundary (in an upstream direction) by mixing alone.

The form of distribution that was eventually chosen to represent the mixing in the Thames Estuary was that shown in Fig. 9. A proportion P_1 of the water originally within the immediate vicinity of O is assumed, after a period of one tide, to be uniformly dispersed (in terms of amount per unit length) through-out a distance of 6 miles seaward of O—this is 2 or 3 miles less than the average tidal excursion. A proportion P_2 is similarly distributed upstream of O. The rest of the water returns to (or remains in) the immediate neighborhood of O. This is a very flexible type of distribution with only two arbitrary constants to be determined. If the mixing is very intense it is to be expected that $(P_1 + P_2)$ will be almost equal to unity, so that little of the original water is left at O, while if the mixing is slight $(P_1 + P_2)$ will be small.

The magnitudes of the mixing proportions (P_1 and P_2), which vary from point to point in the estuary, may be found from two equations: one expressing the net transfer of water through any cross-section by mixing alone (this must be zero), and the other expressing the transfer of salt. The two equations have no algebraic solutions and the values of P_1 and P_2 have to be approached by successive approximations, by relaxation methods or by numerical integration. No details of the equations are given here as the subject has been dealt with at considerable length in an earlier publication (5). In this work use was made of the extensive records of the flow of fresh water entering from the upper river at Teddington (provided by the Thames Conservancy) and of the salinity of the water of the estuary (supplied by the London County Council); details of the dimensions of the estuary were obtained from the Port of London Authority.

It may be mentioned that the values of P_1 and P_2 that were found appeared to be reasonable; thus, nowhere did either value become negative, and nowhere did the sum of the two exceed 0.9; also P_1 was always greater than P_2 (as required by the asymmetry of mixing), and the maximum value of each was found a short distance below Gravesend near where the configuration of the estuary is rather irregular. No reliable figures could be obtained for the first 10 or 15 miles from the head of the estuary, owing to the very low salinities and to uncertainties in the amounts of salt coming from landward sources.

After the values of P_1 and P_2 had been evaluated the accuracy of this method of representing the mixing was checked by predicting the changes in salinity to be expected during periods when the flow was changing rapidly—given only the initial salinity distribution and the daily figures for the flow at Teddington. The distribution

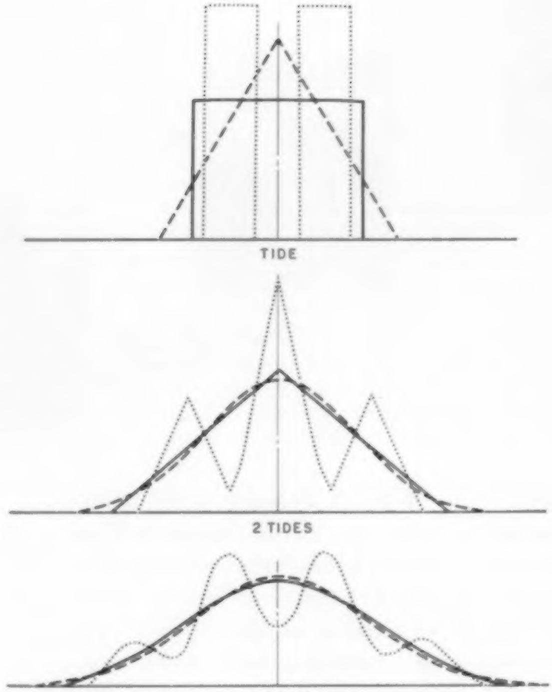

Fig. 8—Distribution of water after periods of one, two and three tides, using three different representations of symmetric mixing

after two different periods of a fortnight, in one of which the flow was increasing and in the other decreasing, was predicted with gratifying accuracy. Calculation of the yearly average distribution of salinity during 1946 also showed satisfactory agreement with the observed values.

The method of using this theory of mixing in calculating the distribution of heated effluents discharged to the estuary will be considered in a later section. Perhaps it should be pointed out that the magnitudes of the mixing proportions are likely to be affected by variations in the tidal and fresh water flows; no attempt has been made to obtain the values of P_1 and P_2 at spring tides and at neap tides, but since the results will only be applied to calculating average conditions over a period of three months, and since the salinity checks showed good agreement for a

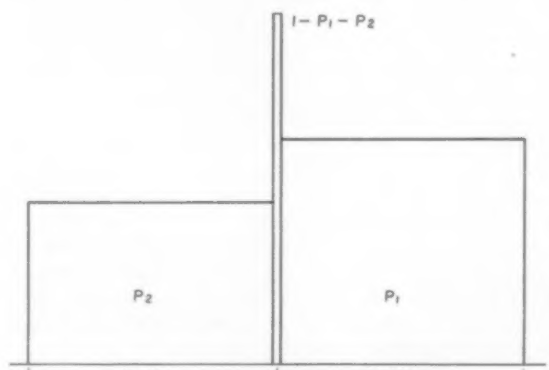

Fig. 9—Representation of mixing during one tidal cycle in the Thames Estuary

period of a fortnight, there is no reason to doubt the applicability of the values used. The effect of variations in the fresh water flow is likely to be slight—except in the first few miles for which the proportions have been calculated.

Mechanism of Heat Exchange.—Even in the absence of any artificial heating there is constant exchange of heat between the water of the estuary and its surroundings. Radiation, evaporation, conduction and convection all play a part, and it is to be expected that the amounts of heat transferred by each of these factors will alter when the temperature of the water is raised by the addition of heat. It is convenient to consider the temperature of the estuary at any point to be composed of two parts, thus

Water Temperature = Basic Temperature + Temperature Increment

where the basic temperature is the temperature that would have obtained under the conditions of slight artificial heating considered earlier in the paper, and the temperature increment is that part of the temperature that is attributable to the additional heat. It is also convenient to consider the heat content of the water to be similarly composed: the excess heat is then the increase in the heat content since the period to which the basic temperature refers. It is the relation between the excess temperature increment and the added heat that is now to be examined. First let us consider what exchanges of heat between the estuary and its surroundings are continually taking place and how the net exchange is likely to be altered by the addition of heat to the estuary.

It is presumed that the daytime heating of the water by the sun is responsible for the average water temperature being higher than the average air temperature (Fig. 3*a*). The heat received from the sun will not be affected by raising the water temperature a few degrees, but the radiation of heat from the estuary will be increased in the presence of heated discharges. The increase in the rate of loss of heat due to additional radiation is likely to be small compared with the increases due to other processes, and over the range of the few degrees by which the water has been heated the increased loss of heat from unit area of surface will be nearly proportional to the increase in temperature.

Evaporation from the water surface causes cooling, and the rate of evaporation depends on the temperature of the water, the temperature and relative humidity of the air in contact with it, the wind velocity, and the fetch of the wind (8). The vapor pressure at 0, 10, 20 and 30 C is 5 mm., 9 mm., 17 mm and 32 mm of mercury respectively; over any range of 5 C the rate of change of vapor pressure with temperature is nearly linear, and so, if other conditions remain the same, it is probable that the increase in the rate of loss of heat by evaporative cooling is proportional to the increase in temperature, the constant of proportionality, however, increasing with rising basic temperature. As the meteorological factors which influence the rate of evaporation—particularly humidity and wind velocity—vary seasonally, and are therefore correlated with the basic temperature, it is impossible to estimate in what manner the constant of proportionality might vary.

The remainder of the heat losses will be by conduction to the sides and bed of the estuary, and by conduction and convection to the air. The increased loss to the bed due to the heat increment will be proportional to the temperature increment, to the thermal conductivity of the bed, and to the wetted perimeter. The increased loss to the air, over the temperature range that is involved, is likely to be nearly proportional to the temperature increment and to the width of the estuary; the constant of proportionality may be expected to be affected greatly by surface turbulence and wind velocity, and may also depend on the relative temperatures of air and water.

The order of magnitude of the difference in the amounts of heat passing through the bed when the estuary is receiving heated discharges and when it is at the basic temperature can be estimated in the following way. If at some point in the estuary the basic temperature is T and the temperature increment is θ, and if at some point a long way below the bed the temperature is T_0 (and this temperature is not changed significantly by changing the temperature of the estuary by the amount θ), then the rate of transfer of heat through unit area at some point nearer to the bed of the estuary will be $b(T-T_0)$ if the estuary is unheated and $b(T+\theta-T_0)$ if it is heated—where b is a constant involving the thermal conductivity of the bed and the spatial arrangement of the points considered. The difference between these two rates is $b\theta$, which is equal to the rate of transfer of heat at the same point if the temperature of the estuary were $T + \theta$ and the temperature at the point a long way below the estuary were T. Consider next the rate of escape of heat from the estuary under these conditions if the bed of the estuary were only 1 ft thick and if beyond that depth the temperature was maintained at the basic temperature. The thermal conductivity of the bed is unlikely to exceed four units of 10^{-3} cal/cm, C, sec; using this figure and a typical observed distribution of θ along the estuary it is found that the rate of loss of heat would be about one-third of the rate of addition of heat that produced the temperature rise. Now the total rate of transfer of heat through one isothermal surface below the estuary will be the same as for another, except for the heat that escapes from the banks to the air; consequently, since the estuary is, for the most part, hundreds of feet wide, the heat passing through an isothermal surface about 2 ft below the estuary will be nearly as great as that passing through the one at half that depth. Clearly, therefore, the effective depth of the bed must be very much greater than 1 ft so that it is unlikely that the amount of the excess heat lost through the bed amounts to more than a few per cent of the total. At all events, it is probable that the change in the amount of heat transferred through the bed of the estuary due to heating of the estuary is proportional to the increase in temperature.

Taking all these things into account, it seems a reasonable hypothesis that if the temperature of the estuary water were increased by artificial heating, so that the temperature at any point were raised from T to $T + \theta$, then the rate of loss of the added heat, per unit area of the water surface, would be equal to $K\theta$. Both T and θ vary with position in the estuary (Fig. 6, Part I), and it is to be expected that K will vary both with position and with the basic temperature—quite apart from the short-term variations, which may be large, but which do not concern the present work.

If, after taking into account the ways in which heat is lost from the estuary, it had been concluded that the

relation between the rate of addition of heat and the consequent rise in temperature was markedly non-linear then the whole argument which follows would be invalid. For instance, had the rate of transfer of heat been proportional to the square of the excess of the temperature over some particular temperature T_0, then at the basic temperature the rate of loss of heat would be $K(T-T_0)^2$, and when the temperature increment was θ would be $K(T+\theta-T_0)^2$; the difference between these two rates is $\theta[2(T-T_0)-\theta]$, a factor involving the basic temperature as well as the square of the temperature increment. On the other hand, if the relation is linear the two expressions become $K(T-T_0)$ and $K(T+\theta-T_0)$ respectively, and the difference between them is $K\theta$, which does not involve the basic temperature. This shows that if relation between temperature increment and heat loss is linear it does not matter if the basic temperature T refers to a time when there was some artificial heating, provided that the changes in heating that have produced the temperature increment are known; in fact, θ need only represent the change in temperature distribution from one period of heating to another. For the present work, however, it was decided, after considering the data available for the observed temperature and the heat inputs, that the basic temperature should refer to conditions under which there was only a very small amount of artificial heating. Another consequence of a linear relation is that the effects of a number of discharges are additive—this would not be so if the rate of loss of heat was not proportional to the temperature increment.

The Exchange Coefficient, f.—For a given loss of heat the corresponding change in temperature is inversely proportional to the depth of the water; the rate of change of temperature increment by a body of water may be written:

$$\frac{d\theta}{dt} = -\frac{f}{z}\theta \qquad (6)$$

where z is the mean depth (defined in this work as the cross-sectional area of the estuary at the instant when the water level is midway between average high and low water, divided by the surface width under the same conditions); the constant of proportionality f is seen from the equation to be defined as the rate of loss of temperature, per unit of temperature increment, from water of unit depth. It is also seen that this coefficient has the dimensions of a velocity; in the present work it will be expressed in centimeters per hour ††† and referred to as the exchange coefficient (the same term as has been used for the exchange of oxygen between the air and water when measured in the same units (1).)

Average Value of f.—An average figure for the exchange coefficient is readily obtained, simply by equating the total rate of entry to the total rate of loss of excess heat. If δQ is the rate of loss of heat between distances x and $x+\delta x$ from the head of the estuary, then

$$\delta Q = -(yz\delta x)\rho\sigma\frac{d\theta}{dt} \qquad (7)$$

where y is the width of the estuary at the point considered —and thus $(y\,z\,\delta x)$ is the volume of the element between x and $x+\delta x$ —and ρ, σ are the density and specific heat respectively of the water. Combining equations (6) and (7) gives

$$\delta Q = \rho\delta y\theta f\delta x$$

The total rate of loss of excess heat from the estuary is then

$$Q \;=\; \rho\sigma f\int y\theta dx \qquad (8)$$

where the integration is carried out from the head of the estuary to the point where the temperature increment vanishes, or, if it is impracticable to extend the integration so far seaward, it can be terminated at any convenient point and the heat lost through the boundary added to the right-hand side of the equation. Under steady conditions this total rate of loss of heat will be equal to the rate of entry of heat to the estuary, which is known and thus gives a value for Q. Equation (8) may now be solved for f(the average value of the exchange coefficient). In this way a figure of 4.0 cm per hour was obtained for f in the Thames Estuary during a particular period of three months.

Principles of Calculating Temperature Distributions.—Consider now the dispersion and cooling of a heated effluent discharging continuously to some point in the estuary, and for the present purpose assume that within a short time of entering the water the effluent mixes uniformly over the cross-section of the estuary. We shall examine in turn four processes that, in fact, occur simultaneously in the estuary, and having discussed them we shall then see how the actual calculations of the temperature distribution were made.

First, there is the tidal movement. In the absence of any fresh water flow and of any longitudinal mixing along the estuary the incoming discharge would be distributed throughout the length of the tidal excursion—which, in most of the estuary, is between 8 and 9 miles for average tidal conditions.

Secondly, from the moment that the discharge has caused a rise in temperature of the water at the surface of the estuary it has been losing heat in accordance with equation (6).

Thirdly, there are the effects of mixing to be considered. Each body of water in the estuary is continually spreading outwards in a manner that may be represented by the mixing theory outlined above.

Finally, there is the effect of the fresh water flow from all points landward. When allowance is made for this, it is clear that the water sweeping past the outfall will be displaced progressively toward the sea, so that the body of water receiving the effluent during one tidal cycle will not be composed of entirely the same water as in the previous cycle, even a part from the effects of tidal mixing.

These four effects, which occur simultaneously, have now to be treated mathematically, either so as to calculate the temperature distribution from a knowledge of the heat transfer coefficient f, or else to calculate f from the observed distribution. In practice the two problems are solved in almost identical ways, as the only way of finding f is by trying different values, calculating the temperature distribution, and comparing it with that observed. The method that was used was to take two values of f, one above and one below the figure of 4.0 cm per hour found for $\bar{f}$, and to calculate two distribution

††† The authors are aware of the mixed systems of units used in this paper. It is found convenient, however, to use ft, miles and Btu, but deg C and cm per hour. For fresh water, 1 cm per hour is equivalent to 2.04 Btu per F, ft² hour.

curves. By comparing these curves with the corresponding observed distribution it was then possible to decide whether or not the value of f appeared to change appreciably along the estuary, and if not what was the most likely value of this coefficient. Figures of 3.7 cm and 4.5 cm per hour were used for f in these calculations.

Before proceeding to the mechanics of the calculations it should be noted that, whereas it was convenient to develop the mixing theory in terms of the mixing during one tidal cycle, the calculations are shortened by using a two-tide period of mixing for which a mixing length of 9 miles is used; the appropriate mixing length is proportional to the square root of the mixing period, and since the original choice of 6 miles was to some extent an arbitrary one, the value of $6\sqrt{2}$ miles may, for convenience, be replaced by that of 9 miles. The mixing proportions P_1 and P_2 for the Thames have, in fact, been calculated for periods of one-half, one and two tides.

Mechanics of Calculating Temperature Distribution.—Consider the changes in temperature which occur during a period of two tides—a time which is hereafter denoted by τ. During this time the water of the estuary is heated by discharges of heat, is displaced toward the sea by the entry of fresh water, and is cooled by the loss of heat to its surroundings; in the calculations it is possible to treat these three processes in effect as a single process. At the same time the water is being mixed, and in accordance with the mixing theory which has been outlined these changes can then be considered as two processes which take place consecutively, although in the estuary they occur simultaneously. The changes in temperature that would occur during the time τ in the absence of mixing are first calculated, and at the end of the time τ the water is mixed according to the known values of the mixing constants.

During the time τ the water will be displaced by the flows of the Upper Thames and other discharges. If at half-tide the volume of water lying upstream of a point a distance x from the head of the estuary is V, then after two tides this water will have been displaced to some point $x + \Delta x$ for which the half-tide volume is $V + \Delta V$, where ΔV is the total discharge during that time from all points upstream of $x+\Delta x$. The displacement Δx can be calculated from a knowledge of the rates of entry of fresh water and the cross-sectional area of the estuary.

While being displaced the water is cooling in accordance with equation (6), which on rearrangement and integration gives

$$\int_{\theta_0}^{\theta_\tau} \frac{d\theta}{\theta} = - \int_0^\tau \frac{f}{z} dt,$$

or

$$\theta_\tau = \theta_0 \, exp\left\{ - \int_0^\tau \frac{f}{z} dt \right\} \tag{9}$$

No account has yet been taken of any additional heat the water has received during the displacement. The heat added by each discharge must be distributed throughout the volume of water to which it is discharged. In practice this has been done by dividing the heat discharged during a period of two tides (24 hours 50 minutes) by the thermal capacity of the water passing the outfall between high and low water as the result of tidal oscillation; the volume of this water is thus the difference between the volumes of water from Teddington Weir to the point of discharge at high water and low water. Adding together the temperature increases due to all the discharges that affect the temperature at any particular point, and dividing by τ, gives the rate of increase in temperature at that point; this rate will be denoted by H.

Between the times t and $t+\delta t$ since the beginning of the period τ the entry of heat will increase Θ by $H\delta t$, where H refers to the half-tide position of the water at time t. During the remainder of the period this increase is reduced by cooling to

$$H\delta t \, exp\left\{ - \int_t^\tau \frac{f}{z} dt \right\}$$

and the total increase in temperature due to the heat entering during the displacement will be found by integration of this expression. Adding the effect of cooling given by equation (9), and using subscripts to indicate position instead of time, the total net change in temperature during the displacement is given by

$$\theta_{x + \Delta x} = \theta_x \, exp\left\{ - \int_0^\tau \frac{f}{z} dt \right\} + \int_0^\tau H \, exp\left\{ - \int_t^\tau \frac{f}{z} dt \right\} dt \tag{10}$$

In general the integrals in equation (10) have to be evaluated numerically and in practice this has been done by dividing the displacement, Δx miles, into n intervals of 1 mile and a remainder of a fraction of a mile. Values of H and $1/z$ were then found for each mile; those for H by taking the mean value for the mile and those for $1/z$ by taking the average value of the reciprocal of the mean depth throughout the tidal excursion (under average tidal conditions) about the beginning of the mile.

Let t_i be the time taken for the water to pass through the ith mile from x, and t' the time from $x + n$ to $x+\Delta x$, and let H_i, z_i be the average value of H, z in the ith mile—found in the way described above. Then, if within the range x to $x + \Delta x$ the coefficient f may be taken to be constant, equation (10) may be represented in numerical form with sufficient accuracy by

$$\begin{aligned}\theta_{x + \Delta x} = {} & \theta_x \, exp\left\{ - f\left[\sum_{i=1}^{n} t_i/z_i + t'/z_{n+1} \right] \right\} \\ & + \sum_{i=1}^{n} H_i t_i \, exp\left\{ - f\left[t_i/2z_i + \sum_{r=i+1}^{n} t_r/z_r + t'/z_{n+1} \right] \right\} \\ & + H_{n+1} t' \, exp\{ -ft'/2z_{n+1} \}\end{aligned} \tag{11}$$

This equation is the one that would now be used in calculating any temperature distribution in the estuary; however, it was not until nearly the end of the work that the processes of heat addition, cooling and displacement came to be treated in effect simultaneously, and various less accurate forms of equation (11) were used at one time and another as the method developed. Nevertheless, while such approximations must have introduced errors to the calculations, these will not have been sufficiently large to affect substantially the value found for the exchange coefficient or to invalidate the conclusions of this article.

When the displacement is less than 1 mile the summation terms in equation (11) vanish, z_{n+1} becomes z_1, t' becomes τ, and the equation reduces to

$$\theta_{x + \Delta x} = \theta_x e^{-f\tau/z_1} + H_1 \tau e^{-f\tau/2z_1} \tag{12}$$

The change in temperature due to the mixing of the water must now be calculated. According to the representation of mixing developed above, the water is considered to be composed of water which lay within 9 miles on either side of the point before mixing took place. The contribution to the temperature at x, made by the water which mixes back from the section of the estuary below this point is

$$\frac{1}{9A_0}\int_0^9 A_s\theta'_s P_2 ds$$

where subscripts 0, s refer to distances from x, and Θ' is the temperature distribution before mixing—that is, as given by equation (11). The contribution from the part of the estuary upstream is

$$\frac{1}{9A_0}\int_{-9}^0 A_s\theta'_s P_1 ds$$

and the contribution from the water that is considered not to have moved is $\theta'_0 (1 - P_1 - P_2)$. Putting $X = AP_1$ and $Y = AP_2$ the temperature increment after mixing is then given by

$$\theta_0 = \frac{1}{9A_0}\left[\int_{-9}^0 \theta' X ds + \int_0^9 \theta' Y ds + 9\theta'_0 (A - X - Y)_0\right] \tag{13}$$

Equation (13) (like equation (10)) has to be modified so that a sufficiently accurate numerical solution can be obtained; the form that has been used is

$$\theta_0 = \frac{1}{18A_0}\left[\left\{\theta'_{-9}X_{-9} + 2\sum_{i=-8}^{-1} \theta'_i X_i + \theta'_0 X_0\right\} + \left\{\theta'_0 Y_0 + 2\sum_{i=1}^{8} \theta'_i Y_i + \theta'_9 Y_9\right\} + 18\Theta'_0[(A - X - Y)_0\right] \tag{14}$$

Iteration Method of Calculation.—Under steady conditions of tidal flow, fresh water flow, heat addition, cooling and mixing, an equilibrium distribution of temperature along the estuary will be attained. This distribution cannot be arrived at in a single calculation since the Θ_x of equation (11) is the Θ_0 of equation (14); starting with any chosen distribution of temperature, applying equation (11) at intervals of 1 mile throughout the estuary, plotting the distribution found for $\theta_x{+}\Delta_x$, reading off at the mile points to give values of Θ', and using these values in equation (14) gives the distribution θ_0 that would be expected after a period of two tides under the conditions governed by the chosen values of f, H, *&c*. Repeating this process a sufficient number of times will give a distribution that is sufficiently close to the required equilibrium distribution of temperature; the same distribution will be approached whatever the distribution chosen initially—but the nearer the initial distribution is to the equilibrium one the less will be the number of iterations required. From the nature of equations (11) and (14) it is clear that a single iteration involves a very considerable amount of work when a distance of about 40 miles is being examined; the work can be shortened by using intervals of 2 to 3 miles in the early stages. There are two ways of carrying out these iterative processes: one is by the manual operation of automatic or semiautomatic calculating machines, with the operators making intelligent guesses as to where the final curve will lie (and experience in the work saves many tedious iterations); the other is to make use of electronic computers, in which case the iterations may be carried out a large number of times in a few seconds. Both methods were used in this work, and both were very time-consuming—for instance, preparing the data for use in the A.C.E. at the National Physical Laboratory included punching holes in some 10,000 Hollerith cards.

The Laboratory's weekly temperature surveys did not extend far enough upstream to allow the curve for the distribution of the observed temperature, adjusted to half-tide, to start from more than 10 miles above London Bridge. For the purpose of these calculations the estuary has been considered to start at this point; the first input of heat is then one at 10 miles above London Bridge and equal to the excess of the observed over the basic temperature, multiplied by the fresh water flow past that point. It follows then that the observed and calculated curves must meet at this point in the estuary.

Magnitude of f.—It was stated, near the beginning of this article, that the average distribution of the observed temperature had been found for ten quarters of the years from 1951 to 1954; for each of these quarters the corresponding calculated distribution has been found by the methods described above. In making these calculations it was assumed that the coefficient f was constant throughout the estuary; two distributions were found for each quarter—one with f = 3.7 cm and one with f = 4.5 cm per hour. The observed and predicted temperatures for the third quarter of 1954 are compared in Fig. 10. It is seen that, except near the temperature maximum, the agreement between the observed and predicted curves is reasonable, and that the coefficient of 3.7 cm per hour gives the closer fit. The difference between the two calculated curves is not very great, and, consequently, it is not possible to say with any great accuracy what is the most suitable value for the coeffi-

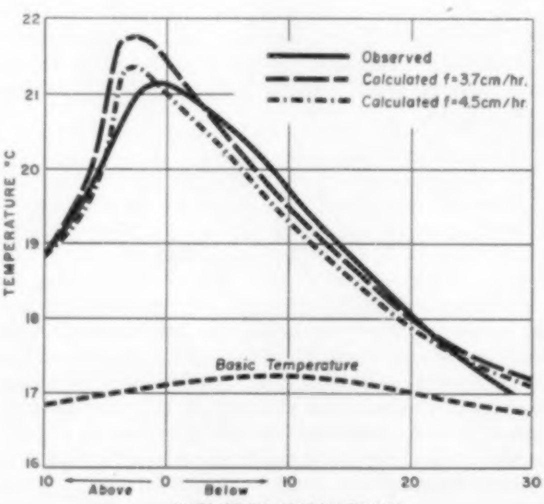

Fig. 10—Comparison of observed average temperature distribution in third quarter of 1954 with distributions calculated for two rates of cooling

cient. It may be noted that even if f were equal to zero, the general shape of the predicted curve would be much the same; a rising curve where the addition of heat has most effect on the temperature, followed by a falling off due to the dilution with water entering from sea.

There is a marked discrepancy between the observed and predicted curves in the vicinity of the temperature maximum. This may well be attributable, at any rate to some extent, to the fact that in this section of the estuary the temperature is found to vary appreciably over the cross-section. A factor that might be thought to account for the broader peak of the observed curve is that the position of the maximum depends, to some extent, on the fresh water flow; the calculated curves are for a steady flow at Teddington of 506 m.g.d., while the observed curve relates to a period for which the average flow was 506 m.g.d., but with the daily values ranging between 278 and 1041 m.g.d. Nevertheless, even when the predicted curve for f equal to 3.7 cm per hour is obtained by combining, in equal proportions, the corresponding curves for 200, 300, 500 and 1000 m.g.d., the resulting curve is found to have a much sharper peak than has the observed one. Broadening of the curve is also to be expected from variations in f about its mean value for the quarter: when the air is calm, warmer than the water, and saturated with water vapor the rate of loss of heat must be very slow compared with that under average conditions, consequently the range of values of f that occur in a period of three months is likely to be large; the general effect of such variations will be to reduce the curvature of the temperature distribution.

In Fig. 11 the predicted and observed curves for all ten quarters are shown, together with the curve for the basic temperature; a value of $f = 3.7$ cm per hour has been used in obtaining the predicted curve. From these curves it seems reasonable to draw the following conclusions: the average rate of decrease of temperature increment is well represented by the use of the coefficient equal to 3.7 cm per hour; there is insufficient evidence to show that f varies with temperature, fresh water flow, quarter of the year, or position in the estuary; the distribution of temperature in the neighborhood of London Bridge is not calculable with as great accuracy as is the temperature at other points in the estuary; the agreement between the observed and predicted curves is generally closer than might be expected from the errors involved in estimating the basic temperature; the large discrepancy between the two curves for the fourth quarter of 1954 (the first diagram in Fig. 11) is probably due mainly to such an error in the basic temperature—since the observed temperature has fallen to the basic temperature by 30 miles below London Bridge and at that point is still falling.

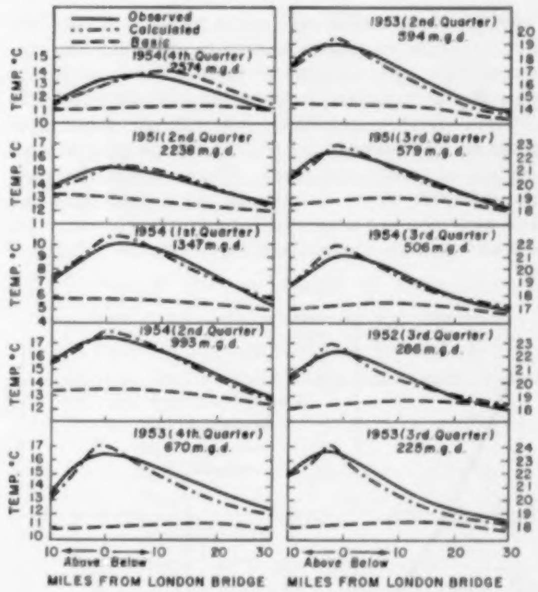

Fig. 11—Observed temperatures in the Thames Estuary during ten quarters in 1951–1954, compared with those which would be expected if no heat were discharged (basic temperatures), and those calculated from the heat discharged, assuming $f = 3.7$ cm per hour. The year, quarter and average flow at Teddington in million gallons per day are shown for each set of curves

Application of Methods Used

Having established the general validity of the theory and methods developed above, it is now possible to calculate, within reasonable limits of accuracy, the effect on the temperature distribution if heat is discharged at any point in the estuary. It is necessary, of course, to know the rate of discharge of heat and also the fresh water flow past each point in the estuary.

Unit Input Curves.—Three sets of distribution curves have been calculated for inputs of heat at a rate of 10^{10} Btu per day at intervals along the estuary; the three families of curves refer to different flows at Teddington, namely, 170 m.g.d., 500 m.g.d., and 1500 m.g.d. A selection of the curves for 500 m.g.d. is shown in Fig. 12; for the input at Teddington (−19 miles) the temperature rise at the point of input is 1.1 deg C—the early part of this curve has been omitted so as to keep the vertical scale as large as possible.

It is to be expected that in the upper reaches the temperature rise for a given heat input will be nearly proportional to the fresh water flow, while in the lower reaches—where the dispersal of heat is the result of tidal mixing rather than fresh water displacement—variations in the flow will have only a slight effect. This is seen in Fig. 13, where the effects of flow on the temperature distribution are compared for inputs of heat at Teddington and at 10 miles below London Bridge.

Fig. 12—Increase in temperature of the Thames Estuary that would be caused by discharge of 10^{10} Btu per day at various points. Flow at Teddington 500 m.g.d.

From the three sets of unit input curves it is possible, by interpolation or extrapolation, to estimate the distribution of temperature due to an input of heat of 10^{10} Btu per day at any point in the estuary under any likely condition of fresh water flow. The estimated temperature rise for any other input of heat will be proportional to the rate of addition of heat. These curves, it should be remembered, apply to average tidal conditions and assume that the discharges of heat and fresh water are steady and that the value of the coefficient f is 3.7 cm per hour.

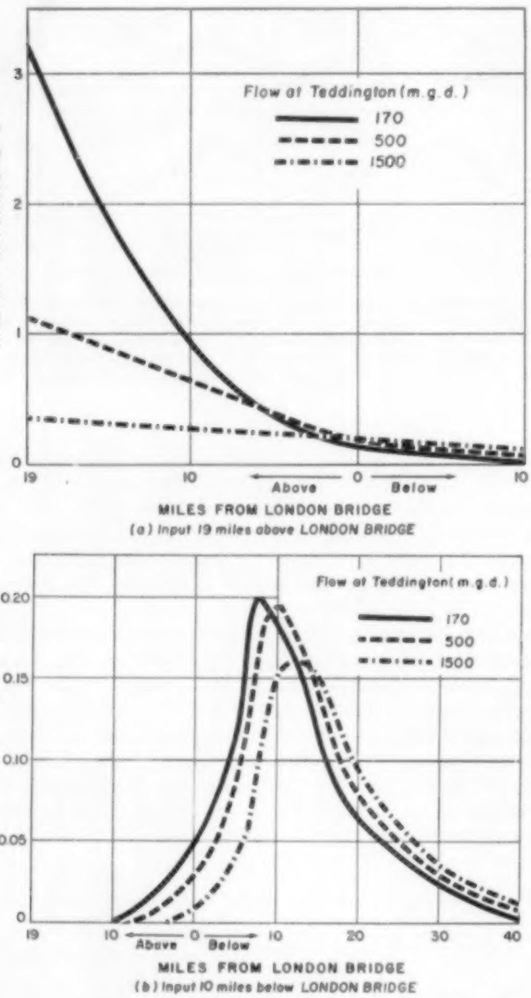

Fig. 13—Comparison of effects of fresh water flow on distribution of temperature due to inputs of 10^{10} Btu per day at two points in the estuary

Position of a Discharge.—As an example of the application of the unit input curves, we may calculate how the temperature distribution in the third quarter of 1954 would have been affected if the heat rejected from Battersea Power Station had entered the estuary not at 3.6 miles above London Bridge but 20 miles below it.

The average flow at Teddington during this quarter was 506 m.g.d., which is sufficiently close to 500 m.g.d. for the curves of Fig. 12 to apply. From the curves that have been calculated for −10, −5, 0, and 5 miles below London Bridge an interpolated curve for −3.6 miles can be produced. This curve, like those from which it was derived, refers to an input of 10^{10} Btu per day; the average rate of heat rejection from Battersea Power Station during the quarter was 25.5×10^9 Btu per day, or 2.55 times as great. Multiplying the interpolated curve by this factor then gives the distribution of excess temperature attributable to this generating station. (If the flow at Teddington had not been close to one of the flows for which unit input curves have been calculated it would have been necessary to interpolate for flow as well as for position; of course, each interpolation introduces some error, but if the most accurate results are wanted a new input curve can always be calculated for the required flow and position).

In Fig. 14 the continuous curve shows the observed temperature distribution during the third quarter of 1954 (the same curve as in Fig. 10) and the dotted curve shows the effect of subtracting the calculated curve for the excess temperature due to the heat rejected at Battersea. Similarly, taking 2.55 times the curve for a unit input 20 miles below London Bridge (Fig. 12), the effect is found of introducing the same amount of heat at this point. Adding this to the dotted curve of Fig. 13, the broken curve is obtained; this then shows the net effect of the removal of the point of entry of the heat rejected from Battersea Power Station from Battersea to 20 miles below London Bridge (that is to Dartford or Purfleet).

Other Systems.—Perhaps the two most important points in the methods that have been used in the work reported in this paper are the theory of tidal mixing and the use of the empirically found basic temperature. It is likely that the same methods may be applied to some other estuaries, but if an estuary is highly stratified—so that there are large vertical gradients of salinity and temperature—the mixing theory will require modification, more intensive and prolonged study of the system will be necessary, and even then it may be found impossible to apply the methods of this paper with sufficient accuracy. For few estuaries will the data for the temperature before heating was appreciable be as full as for the Thames, but, of course, the basic temperature need not refer to a condition of no artificial heating—provided that the relation between the air and water temperatures can be found for some period when the degree of heating was appreciably different from that during the period

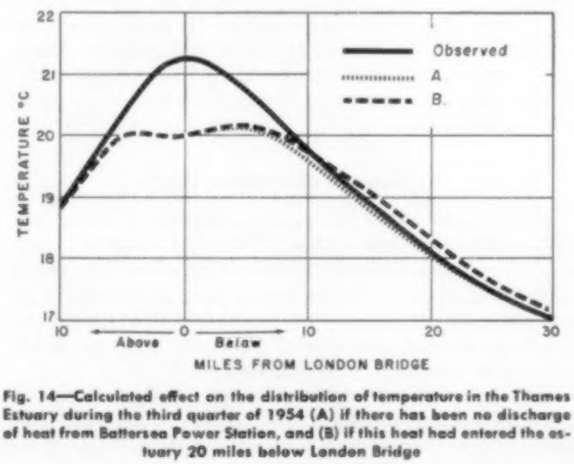

Fig. 14—Calculated effect on the distribution of temperature in the Thames Estuary during the third quarter of 1954 (A) if there has been no discharge of heat from Battersea Power Station, and (B) if this heat had entered the estuary 20 miles below London Bridge

being examined, and that the change in the distribution of heat inputs between the two periods is also known.

The same methods may probably be applied to fresh water streams, but in this case it is unlikely that a mixing theory will be needed; once again there will be difficulties if there is appreciable stratification. One brief survey (9) of the rate of cooling of a river, made by staff of the Laboratory, gave an average value of f equal to 2.6 cm per hour; this figure, taken in conjunction with that of 3.7 cm per hour for the Thames, is probably sufficient to indicate, at any rate roughly, what figure should be used in any similar system for which it is not practicable to make a detailed study.

Acknowledgments

The work reported in this article has been carried out over a number of years and many people have been concerned in it. The authors wish to acknowledge particularly the work of Dr. J. Grindley in obtaining the temperature of the estuary during recent years, of Miss D. S. Rosenbaum and Mrs. P. A. Ogden in calculating the basic temperature, and of Messrs. R. N. Davidson and J. F. Walshe in the remainder of the work.

The authors also thank the London County Council for access to their records of temperature and salinity, the Port of London Authority for hydrographic data and information on heated discharges, the Central Electricity Authority, the London Transport Executive, and the Ford Motor Company, Ltd., for details of heat rejected from power stations, and the Thames Conservancy for figures of the discharge of the River Thames. The article is published by permission of the Department of Scientific and Industrial Research.

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Fuel Cells Under Research

Although fuel cells were first reported in 1802 and the first successful one was made in 1839, interest in this means for creating electricity is just now at its height, with more than 50 industrial, university and government research laboratories working on the problem.

So reported Sidney J. Magram, of the Army Research Office, Washington, in a paper, "Fuel Cells," presented at the opening of a symposium Dec. 6 in Washington, D. C., during the 53rd Annual meeting of the American Institute of Chemical Engineers.

Popular usage has broadened the term fuel cell "so that it may be defined as an electrochemical device in which part of the energy derived from a chemical reaction is converted to electrical energy by a continuous supply of chemical reactants. . . . A fuel cell is a battery wherein the reactants are continuously fed to the electrodes regardless of the chemical reaction involved.

Hydrogen is the fuel and oxygen or air is the oxidant for the most successful fuel cell to date, he said.

Fuel cell reactants may be hydrogen, carbon monoxide, coal, natural gas, ethane, propane, formaldehyde, alcohol, hydrazine, zinc, sodium or magnesium, he said. Oxidants are oxygen, air, chlorine or nitro-organic compounds.

Mr. Magram said that the largest multicell power package today is "the outstanding development of the Allis-Chalmers fuel cell powered tractor," which has 1008 cells with an overall energy density of 170 lb/kw and 1.75 ft³/kw. "It was reported that the fuels consisted of three gases, chiefly propane," but no data were disclosed indicating that the propane was oxidized to carbon dioxide and water.

ASME Annual Meeting Highlights—II

IN this issue we conclude our presentation of abstracts from papers presented at the Annual Meeting of ASME. Since this was one of the Society's most successful meetings with a registration close to 5000 and over 300 papers it was obviously impossible to abstract all of the papers presented.

Chemical Cleaning

William F. Ashton and **Stanley M. Rose,** Sumco Engineering, Inc., collaborated on the paper "Acid Cleaning of Superheaters and Reheaters." The problem of cleaning superheater and reheater elements, the authors began, has concerned the entire power industry, as well as the chemical cleaning contractor.

There have been many cases where nondrainable superheater elements have been cleaned using the conventional "fill-and-soak" method, but these cleaning jobs were confined to low pressure units and entailed the removal of all hand-hole caps in the headers and individual flushing of each tube. This procedure was time consuming and, in many cases, effective cleaning was not accomplished due to the stagnation of spent solvents in tubes that were heavily fouled. As steam-generator design advanced, superheaters and reheaters were fabricated in an all-welded construction, thus eliminating any possibility of individual flushing of elements.

The investigation of flow characteristics proceeded from the theory that the solvent flow should, as nearly as possible, approximate the operational flow through the unit to be cleaned. For example, a million pph boiler would require a flow of approximately 2000 gpm with approximately $1^1/_2$ to 2 ft per velocity through the parallel elements.

These velocities proved to be effective in sweeping air and other gases from nonventable loops and entraining them in fluid flow. It was found that distribution of flow through the parallel elements was uniform enough to anticipate favorable field results.

Both the removal of mill scale and the removal of operational deposits pose several common problems and several distinctly opposite problems. The authors' company launched a study designed to reconcile any disadvantages in order to provide for one single method, which would be economical with regard to the type of equipment utilized, methods, and procedures. These facts developed:

1. With high flow through the units, with steam applied to the solvent externally to the boiler, preheating could be accomplished regardless of what mill scale or operational deposits were present.

2. The choice of acid narrowed to two solvents, inhibited hydrochloric and inhibited citric acid. Both acids could be used safely with regard to corrosion and erosion.

3. While it is not within the scope of this paper to discuss the relative properties of the two acids, it was concluded that hydrochloric acid could be used for both type deposits, being limited in its use to units containing only carbon steel, due to the problem of chloride corrosion cracking in stainless steel at boiler operating temperatures. It was also concluded that, generally speaking, citric acid could be used for both type of deposits but particular emphasis had to be placed on flow, higher temperature, and time of retention in the units. In addition, the chelating ability of citrate would prevent deposition in nondrainable areas.

4. It was concluded that a single method, utilizing a Hi-Flo technique, could be applicable for removal of both mill scale and operational deposits except for the following: Use of any solvent would depend upon material of construction, type of deposit, and modified method of high flow with the use of hydrochloric acid.

Following this background material the authors described in quite some detail their field experience with cleaning both drainable type superheaters and reheaters with nonventable loops and pendant type units.

William E. Bell, Charles Pfizer and Co., then discussed "Chemical Cleaning with Citric-Acid Solutions." Specifically, he discussed the difference between citric acid and ammoniated citric acid when reactions with steel or iron oxides are involved.

Within the past 18 months, many cleaning operations with citric acid-based solutions have taken place. Most of these were preoperational cleaning using inhibited citric acid. Ammoniated citric acid solutions were used in only a few instances to our knowledge. The reactions between citrate ion and steel, ferrous ion or ferric ion have not been completely described in the technical literature, and when these reactions each take place at the same time, as during chemical cleaning, control procedures and interpretation of results can be most difficult. It is a fact that the utility of citric acid in chemical cleaning is more advanced than the science.

Mention of ammonium citrate for rust and scale removal from ferrous metals has often appeared in the literature, and over a period of years, some ammonium citrate has been sold for this purpose. Loucks, Morris, and Pirsh mentioned ammonium citrate and stated that further investigation of this chemical is advisable.

Most deposits to be removed by chemical means involve scales and oxides which contain iron in the ferrous state. In addition, the slight but uniform, corrosion of acid solutions provides a reducing atmosphere which can reduce ferric ion to ferrous ion. Ammoniated 3 per cent citric colutions (pH 3.0–3.5) can be used for cleaning under such conditions without precipitating ferrous acid citrate. Citric acid solutions for cleaning under such conditions can be used when it is known, or calculations show, that the solubility limit of ferrous acid citrate will not be exceeded. The data presented show that this limit is near 0.40 per cent ferrous iron.

Another advantage of ammoniated citric acid solutions is the lower inherent corrosion of bare metal. Ability and efficiency in dissolving red rust are equal to those of citric acid.

The advantages which have led to the use of, and interest in, citric acid also are obtained in ammoniated citric acid—no chloride ions to lead to stress-corrosion cracking and low toxicity.

In closing, the authors stated that they are especially interested in continuing experiments which show that ammoniated citric acid solutions also react with operational magnetic iron-oxide deposits more quickly and completely than citric acid solutions.

Corrosion Control in Furnaces

In several sessions, two sponsored by the Corrosion and Deposits Committee and all three by the Fuels Division, the perplexing problem of corrosion attacks in the various boiler heat transfer components was discussed. We group the papers in this one report for convenience sake.

W. D. Niles and **H. R. Sanders,** Esso Research and Engineering Co., teamed up to present the paper "Reactions of Magnesium with Inorganic Constituents of Heavy Fuel Oil and Characteristics of Compounds Formed." The authors stated at the outset that high-temperature corrosion caused by trace quantities of metals together with sulfur is a continuing problem in heavy-fuel-oil operation, particularly in new high-temperature steam boilers and gas turbines. This problem has been attacked with some success in recent years by additives such as magnesium, which react with corrosive metals to form relatively innocuous compounds. For especially severe conditions, water washing has also been used to remove light metals such as sodium.

The present solutions are not ideal, however. For example, use of magnesium additives gives considerably increased deposits. Also, there are a variety of questions still outstanding concerning the additive concentrations needed to do an adequate job under various conditions, the importance of sulfur in high-temperature corrosion and deposits, and the effect of metals in the fuels other than those known to be corrosive.

The authors believed the best key to an improved insight into these problems is a better understanding of the basic chemistry of the sodium-vanadium-magnesium-sulfur systems involved. To this end, a research program was undertaken by Esso Research. This involved checking available literature data on the sodium-vanadium-sulfur system, doing new work on the magnesium-vanadium-sulfur system, and studying the physical behavior of the compounds formed. Based on the knowledge thus obtained, prediction could be made of the compounds likely to be formed under commercial operating conditions. To check this, actual boiler and gas-turbine deposits were analyzed and the results were compared with those expected.

The work confirmed that three different sodium vanadates are formed in reactions of sodium sulfate and vanadium pentoxide depending on the concentrations of sodium and vanadium in the reacting ash. With this knowledge, deposit compositions can presumably be predicted by knowing the Na/V ratio in the fuel if sodium and vanadium are the major metals in the fuel. The corrosion properties of these compounds are quite different.

Analyses of deposits taken from units operating with a magnesium additive have shown various magnesium vanadates formed in the reactions of magnesium with vanadium. However, a knowledge of the type of magnesium vanadate (meta, pyro, or ortho) which will be formed under any specific set of conditions had not been obtained.

In this study, magnesium oxide and magnesium sulfate were reacted with vanadium pentoxide in the same manner as described for the sodium-vanadium-sulfur system. The results showed that the equilibrium compounds formed in the reactions depended upon whether the sulfate or the oxide was used as a reactant.

Analysis of commercial burner unit operating conditions, normal sulfur concentrations in fuels and typical conversion of sulfur to SO_3 showed that in almost all units operating under pressure, such as gas turbines, SO_3 partial pressure is sufficient to cause sulfation of magnesium. Units operating at atmospheric pressure may or may not have sufficient SO_3 partial pressure to sulfate magnesium, depending on the operating metal temperatures.

It is concluded that one of two possible magnesium vanadates is formed in deposits depending on the SO_3 partial pressure. The prediction of deposit compositions this statement makes was verified in three field installations. But this simplified prediction of deposit compositions from the reactions of the binary sodium sulfate-vanadium pentoxide system holds true only when these are the major ash components in the fuel.

Some fuels have ash components other than sodium and vanadium which are present in relatively large amounts. Some of these metals will react with vanadium leaving, in effect, a higher Na/V ratio, which will alter the Na-V compound that should form.

Some heavy fuels have been recognized to cause more severe corrosion in critical boilers and gas turbines than others. In most cases higher corrosion rates have been attributed to either a higher ash content of a fuel or a less favorable relative concentration of vanadium and sodium in the ash. Buckland and others found that in binary mixtures of sodium sulfate and vanadium pentoxide, high-temperature (above 1450 F) corrosion of stainless steel increased markedly when the vanadium-pentoxide content was raised to 66 wt per cent or above. Below 50 per cent vanadium pentoxide, the mixture was only slightly corrosive. The results of the authors' study agree in general with those obtained by Buckland although the ratio of V/Na where maximum corrosion occurred was slightly higher.

Many steam boilers operate with metal temperatures below the melting point of the sodium-vanadium compounds while gas temperatures are well above these melting points. These compounds would strike the surface as a liquid and solidify, passing through the partial melt phase. In this case, deposits would not be expected to reach an equilibrium but would continue to grow.

The magnesium metavanadate was found to be much lower melting than either the magnesium pyro or orthovanadates which are formed at equilibrium. It proved as low melting, in fact, as any of the sodium-vanadium compounds. This metavanadate has the following

melting characteristics: sinter, 790 F; initial melt, 1240 F; and final melt, 1300 F. Because of the time required for the reaction to proceed from the intermediate compound to either of the equilibrium compounds, this intermediate would be expected to exist in significant concentrations on the surfaces exposed to combustion gases. Because of the reaction time required for its disappearance and its low melting characteristics, it was concluded that this intermediate compound is very likely responsible for the excessive deposits found when a magnesium additive is used.

W. F. Cantieri and **R. E. Chappell,** Diamond Power Specialty Corp., supplied a paper on "Slurry Spraying for the Control of Corrosion and Deposits in Oil-Fired Boilers." There are basically three methods of getting the additive into the boiler; namely, mix it with the fuel oil, inject it through the burners or ports in the furnace walls, or spray it on the tubes through soot blowers or other lances. This paper summarizes the authors' company's investigations on the application of slurry-sprayed additives to oil-fired boiler tubes, which have been performed over the past 5 years in co-operation with the Florida Power & Light Co.

A table was presented which summarized some of the tests which have been reported where additives have been used as a measure of controlling deposits on operating boilers. It is significant that dolomite was the most widely reported additive and that none of the investigators reported injection of the additive as a slurry directly onto the slag deposits.

Most experimenters have started with the assumption that some adverse chemical reaction occurs during the burning of oil in an effort to change the chemical reactions during burning. The authors, on the other hand, believe that additives injected into the furnace do not react with the ash until the additive and the ash collect on the tubes.

When a dry additive is injected into the furnace, most of the fine particles follow the gas stream and flow around the tubes instead of sticking to them. The same is true of the ash, only a small portion of it collecting on the tubes. Therefore, the dry addition of additives is a wasteful procedure. Previous work with sprays and soot blowers has convinced the authors that water drops, on the other hand, are not immediately evaporated after leaving a nozzle, but continue with appreciable size for quite a distance into the furnace. By mixing the additive with water, the fine particles are carried by the water drops to the tubes. The mass of a drop is large enough to cause it to strike a tube rather than to follow the gas around it. As a result, a much higher percentage of the additive is available to react with the slag.

Water slurries of additives were sprayed on boiler tubes to prove this theory. Slag treated in this manner was more friable than untreated slag and was easily removed by soot blowers. The quantity of additive was reduced to about $^1/_5$ of that reported by other investigators. As a general rule, starting with a clean boiler, a slurry application once a day is sufficient to control the slag deposits. The normal soot-blowing schedule is maintained.

After the slurry-spraying technique had been developed, boilers were operated for 12 months using a slurry mixture consisting of $^3/_8$ lb of calcium and magnesium oxides per gal of water applied once a day. Examination of the heating surfaces showed the following:

1. Viscous slag, treated with slurry, developed a crust which dislodged in a period of hours from the main body of the slag or from the boiler surfaces.
2. The slag accumulation on the furnace floor was in a pebble form and the pebbles did not fuse together.
3. Deposits in the superheaters and reheaters were in the form of coarse grains which had little adhesive strength.
4. Several thin coats of slurry spray were more effective than one thick coat.
5. Slag deposits which had been treated with slurry sprays were approximately 50 per cent soluble in water.

Florida Power and Light reports that, in general, superheater and reheater hangers, because of their very high metal temperatures, and other uncooled boiler parts located in the high-temperature zone do not receive the degree of protection from slurry spray to prevent deterioration in the course of time.

If additives can reduce corrosion, as the authors believe they can, boiler designs using higher steam temperatures and tube-metal temperatures may be possible in the future. Further, it is believed that the thermal shock produced by slurry sprays can be held at or below that which is typical of a normal long retracting, saturated-steam soot blower. Lastly it was reported that soot-blower controls have been developed to spray the boiler automatically with a minimum of manual labor.

R. Kato and **B. E. Paris,** Foster Wheeler Corp., furnished a report on "Effects of Ammonia Injection on Corrosion in Air Preheaters." Recent tests in Great Britain indicated that the addition of ammonia to the flue gas minimizes air-preheater corrosion in oil-fired boilers. In view of these, the tests reported in this paper were performed to determine the feasibility of injecting ammonia into the flue gas of a large pulverized-coal-fired boiler to minimize corrosion in the air preheater. During the test runs, most of which were of 30-hr duration, the boiler was maintained at constant load. Typical conditions during a test run were given in table form.

Low-temperature corrosion tests on a pulverized-coal-fired boiler generating 320,000 lb per hr of steam at 840 psig and 850 F show the feasibility of minimizing low-temperature corrosion by addition of ammonia. Firing of pulverized coal containing sulfur results in corrosion by the condensation of sulfuric acid on steel when the metal-surface temperature falls below 300 F. The rate of corrosion depends on the metal temperature, attaining a peak at 250 F and decreasing to low values at 300 F and above, and between 150 to 200 F. Injection of ammonia into the flue gas reduces the corrosion rate to negligible values above 150 F, but does not noticeably affect the corrosion below 150 F.

Based on the present cost of ammonia and the results reported herein, the injection of ammonia would cost approximately \$0.50/ton of coal fired.

The cost for the installation and operation of an ammonia injection system in a 2,000,000 lb of steam/hr operating 8000 hr/year is approximately \$50,000/year.

Thus, if the fuel cost is approximately \$10/ton of coal and the stack gas temperature can be lowered 50 F, the use of an ammonia-injection system will save approximately \$50,000/year due to increased thermal efficiency. This is in addition to any savings due to lower fuel costs, less outages, and less air-preheater repairs.

"New Developments for Handling the Fuel-Oil-Ash Corrosion Problem" were presented by **D. W. McDowell, Jr.** and **J. R. Mihalisin,** The International Nickel Co. The oil may be treated, the authors remarked, to remove the vanadium, sodium, and sulfur compounds. Unfortunately, the cost of the treating operation has prevented this approach from furnishing a general solution to the problem. If the oil is to be carried by pipeline or tank car, it may be treated at the refinery to remove some of these corroding agents. In this case the problem is simplified. However, many applications require transport by tanker with the opportunity to pickup additional corrosive constituents from salt water enroute.

Still another approach is the use of the protective coatings. The problems involved in the selection of a protective coating are somewhat similar to those associated with the selection of a corrosion-resistant alloy. Usually if a single specific corroding agent is operating, the choice of a satisfactory protective coating is simplified but as the corroding agents multiply, the selection becomes more difficult. A further problem is related to the temperature of operation and the temperature cycling. The temperature is such in most applications that diffusion rates of the elements used for coatings are quite high and within a short time the protective character of the coating is destroyed. The temperature cycling, of course, introduces problems of adherence of coatings.

Up to the present time, the use of protective coatings for parts which must operate in the range from 1000-2000 F has not proven to be a successful solution to the problem.

Next, is the employ of additives to oil. The primary aim of a good additive is to raise the fusion point of the ash; however, to be of maximum value it should have all of the following properties:

a. The additive must combine chemically with the corrosive agents (vanadium, sulfur, sodium) to produce high melting, stable compounds.

b. It must be cheap. An estimated maximum cost ranges from \$0.001/gal (central station boiler) to \$0.04/gal (gas turbine).

c. It must be commercially available in car-load quantities.

d. It should have a low molecular weight. Experience has shown that most of these additives function by chemical reaction. Thus, for a given atom ratio, the lower the molecular weight, the lower the actual weight of additive needed.

e. The additive must be easily introduced into the system. If it is added as a slurry it should not cause excessive wear on pumps or cause clogging of nozzles.

f. It should function for all the alloys in the system It has been observed that certain additives have retarded corrosion on 25 chromium–20 nickel steel but not on some other alloy compositions.

Generally speaking, the compounds of Mg, Ca, Zn, P, and Al have been found most effective with not much general or specific agreement among investigators. For example, in some studies aluminum appears to have been an effective agent, in other, ineffective. The order of effectiveness changes with temperature which is not too surprising because the relative effectiveness of a group of additives must be related to the stability of their compounds, the order of which may change with temperature. In these residual oils there is usually 2–4 per cent sulfur, so during combustion the sulfate of the metal additive is formed.

If, through design changes, the temperature of continual operation of critical parts can be maintained below 1200 F the situation will be improved. Moreover, there is some experience which indicates that with improved draft more of the harmful deposits can be carried through and out of the system. Less deposit will reside on the parts operating at high temperature and less corrosion will be experienced.

The International Nickel Co., Inc., in cooperation with numerous companies operating steam power stations that were using large quantities of bunker C to fire their boilers, exposed 14 high-temperature test racks containing a wide variety of heat-resistant alloys. The maximum temperature was varied. Also the time the specimens were held at the high temperature was not controlled but the boilers underwent what was considered normal boiler operation except where six racks were exposed in boilers in which various additives were used to inhibit the excessive corrosion rate. Results of these full-scale tests do indicate a need for higher chromium contents in the heat-resistant alloys.

Crucible tests were run for various alloys which have been considered for gas-turbine components. The specimens measured 1 in. $\times$ $^1/_2$ in. $\times$ $^3/_{16}$ in. and had a machined finish. The synthetic ash mixture was 15 per cent Na_2SO_4 and 85 per cent V_2O_5 which is considered the most corrosive combination of these particular compounds. The tests were conducted at 1700 F for times up to 100 hr in stagnant air atmosphere. The technique here was to remove the scale formed in the tests by sand blasting and then reweighing. The data in which per cent loss in weight is plotted versus time indicates an order of merit based on the resistance of these alloys to this type of attack. Such evaluations have been shown to correlate closely with service experience.

The crucible test has been shown to be valuable in screening alloys for resistance to fuel-oil-ash corrosion. The studies described indicate that Na_2SO_4-V_2O_5 crucible tests result only in accelerated oxidation while combinations of a sulfur-bearing gas and molten synthetic fuel-oil-ash constituents result in combined oxidation and sulfidation and more nearly simulate service experience.

The role of "Dewpoint Meter Measurements in Boiler Flue Gases" was covered by **A. W. Black, C. F. Stark,** and **W. H. Underwood.** The Air Preheater Corp. There has long been needed in American furnace operating practice a practical means of rapidly measuring the tendencies of flue gases to form deposits of fly ash or to cause corrosion in such heat-recovery equipment as air preheaters and low-level economizers. Such a means would permit a nearly instantaneous determination dur-

ing furnace operation of the effects of various changes of fuel and operating procedures. British investigators, particularly Corbett, Flint, and Littlejohn, reported their successful use of a dewpoint meter which was designed by the staff of the British Coal Utilization Research Association. Through the use of this instrument they and others have discovered that the temperatures at which the dewpoint meter showed high acid-condensation rates were more significant than the dewpoint temperature itself in assessing the corroding and fouling properties of flue gases.

Since November 1957, dewpoint-meter measurements have been made of the flue gases in eleven different central power stations in the United States.

At present there is not available any adequate method for measuring the rate of fly-ash deposit accumulation in air preheaters. In those installations of air preheaters where such deposits are formed the preheater draft loss increases over a period of time until preheater washing is necessary, thus a convenient practical index is the frequency at which the air preheaters need to be washed.

In practical operation of air preheaters, corrosion of the cold-layer elements is of economic significance in a small minority of steam plants. Fuels or operating conditions which will cause corrosion are likely also to cause heavy accumulation of deposit. When measures are taken to minimize the nuisance of deposit accumulation these same measures will usually minimize corrosion of heating elements. However, when the fly-ash contains large quantities of free sulfuric acid, corrosion of the elements will be rapid.

For conventional fuels when the average cold-end temperature is above the temperature of the maximum condensation rate measured by the dewpoint meter and the condensation rate is low or medium the corrosion rate is negligible. When the average cold-end temperature is below the temperature of the maximum condensation rate and the maximum condensation rate is medium or high, noticeable corrosion of cold-end heating elements occurs.

To control the rate of deposit or corrosion in air preheaters it has long been common practice to prevent the average temperature of inlet air and outlet gas from falling below an initially recommended minimum. This practice has been generally satisfactory especially when the minimum allowable average cold-end temperature has been adjusted for each installation upward or downward as operating experience indicates. Occasionally it has not been practical to increase the average cold-end temperature sufficiently to avoid troublesome deposits or corrosion.

It was interesting to discover that a decrease in boiler load decreased the rates of acid condensation.

Generally boilers in which there is no slagging have the lowest rates of deposit buildup in the air preheaters. Conditions on the exposed surface of the slag also appear to influence the rates of acid formation.

M. Weintraub, S. Goldberg, and **A. A. Orning,** U. S. Bureau of Mines, added to the proceedings their paper "A Study of Sulfur Reactions in Furnace Deposits." External corrosion of certain heat-transfer surfaces in high-pressure, coal-fired boilers is associated with adherent deposits that are rich in alkali metals and sulfur. These elements generally are combined as normal sulfates, pyrosulfates, or more complex compounds, such as potassium ferric trisulfate.

These deposits may contain various amounts of coal ash, and they may be overlaid with ash and slag. They may be found on tube surfaces in areas of flame impingement, principally furnace-wall tubes, or on superheater and reheater tubes. Compounds in these deposits are responsible for bonding ash to tube-metal surfaces. The evidence to date also indicates that corrosion of the metal of such surfaces is significant whenever conditions are favorable for the compounds in the deposit to become liquid. When a liquid phase is present, metal in contact with the liquid will be attacked.

The sulfates found in the deposits do not occur as such in the coal. They must be the result of chemical reactions during combustion, or of reactions between immediate products of combustion and compounds previously deposited on the metal surfaces.

The present investigation by the Bureau of Mines was to study the reactions between samples of fly ash and compounds of sulfur in flue gas. The absorption of sulfur by fly ash when exposed to synthetic flue gas was observed both when the fly ash was placed in a temperature gradient and when placed in a constant-temperature zone. The temperature gradients used were like those found in ash layers on boiler tubes. The observations, at constant temperatures with the same ash, gave comparative data so that the effect of the temperature gradient could be determined. Oxides of sulfur were supplied in the gas stream. Other compounds were limited to those in the fly ash. Results obtained under these conditions indicated what further work should be done.

The experimental data on sulfur absorption by fly ash at first seemed contradictory. The constant-temperature tests showed low absorption at temperatures below 1100 F. The gradient tests showed maximum absorption in the bottom layer where the temperature was certainly below 1100 F since this layer was thin, was protected by the overlying ash, and rested directly on the metal surface at 700 F. The contradiction no longer appeared when it was assumed that the oxidation of sulfur dioxide to trioxide was catalyzed by the fly ash. The catalysis was observed in the constant-temperature tests. A decreasing rate of the catalytic reaction was assumed to explain the low absorption of sulfur at temperatures below 1100 F. Decreasing equilibrium content of sulfur trioxide in the gas explained low absorption at temperatures above 1100 F. Since the layer of fly ash in the gradient tests was exposed to radiation at 2000 F and rested on a surface at about 700 F, temperatures about 1100 F must have existed at some level in the layer. The catalytic oxidation of the sulfur dioxide reached the highest levels attained in the constant-temperatures tests. Accordingly, a comparison of the data showed that the maximum absorption was the same in both the gradient and constant-temperature tests.

Certain facts indicate that sodium and potassium are released from the coal ash and carried in the combustion products in a volatile form, possibly as oxides or hydroxides. These compounds may diffuse through the ash layer and react with sulfur trioxide at the site of deposit. Therefore, hindering the oxidation of sulfur dioxide to sulfur trioxide in the gas stream would not be effective unless the catalytic oxidation in the ash layer was also hindered.

Carl Cain, Jr. and **Wharton Nelson,** Kreisinger Development Lab., Combustion Engineering, Inc., presented the paper "Corrosion of Superheaters and Reheaters of Pulverized-Coal-Fired Boilers, II." A previous paper presented results of laboratory and field studies of high-temperature fireside corrosion of reheater and finishing superheater tubes in modern pulverized-coal-fired boilers. Complex iron and/or aluminum alkali sulfates were shown to be formed in fireside ash deposits and to become corrosive when molten on tubes having steam temperatures above 950 F. The molten compounds migrate through the ash deposit to tube-metal surface as a result of the thermal gradient existing in the deposit, and react with the metal.

The skin-temperature range for this rapid liquid-phase attack is bracketed by (*a*) melting point of the mixture of complex alkali sulfates present, and (*b*) their thermal stability limit. Its range is about 1025–1300 F. Presence of ash deposits on a tube together with metal temperature within these limits are both necessary for rapid corrosion to occur by this mechanism. Stainless-steel shields attached to tube surfaces effectively prevent corrosion, since the skin temperature of the shields is above the 1300 F temperature limit for formation of these corrosive compounds.

Continued studies of the corrosion process have developed additional data concerning the temperature boundaries, corrosion rates, and methods for distinguishing liquid-phase from gas-phase attack on low-chrome ferritic alloys.

The rate of corrosion increases with temperature once the melting point of the corroding complex sulfate mixture is reached. With further increase in temperature its thermal-stability limit is exceeded, and no more complex sulfate can be formed. At metal temperatures above this limit, the corrosion rate again assumes the considerably lower gas-phase oxidation rate.

In the vicinity of 600 F, sodium and potassium pyrosulfate, which are corrosive to metal, would be expected to form and become molten, producing a second corrosion peak. At about 1540 F another corrosion peak might be encountered due to melting of the normal sodium and potassium sulfates. Thus a two-peak curve would result over the whole temperature range found on heat-transfer surfaces throughout the boiler; i.e., from water walls to superheater tubes. The third high-temperature peak due to normal sulfates might occur only on noncooled supports in high-gas-temperature regions.

Experiments were run in the laboratory to confirm these ideas. Corrosion was noted in each of the other two zones, but it occurred in each case at a lower rate than that due to the molten complex sulfates. Potassium and sodium pyrosulfate are in the absence of sufficient iron oxide, extremely corrosive to metal.

The relation of melting point, corrosive range, and sulfur content of the various alkali sulfates were graphically presented. Each type of compound has its characteristic corrosion temperature range; i.e., range in which it is molten and stable. Both melting point and stability of these compounds decrease with increasing sulfur content. The shaded areas of the pyro and trisulfate ranges show the extensions of thermal stability which can be gained in an atmosphere containing a high partial pressure of sulfur trioxide. Mixtures of the various kinds of alkali sulfates of a particular type or of different types can greatly lower the temperature for initial attack.

Further, the temperature range of liquid-phase corrosion varies to a great extent with composition of the liquid phase. Similarly a variation of the sodium-to-potassium ratio greatly affects the melting point of the complex sulfates in an ash deposit. Variation of the corrosion rate is likewise effected by changes in the sodium-to-potassium ratio.

Sulfides are produced by the corrosive reaction of molten complex sulfates on metal and frequently sulfide penetration into the metal structure is observed. Moreover, surface carburization of tubes in the zones of highest corrosion has sometimes been observed even though carbon in the fly ash is very low. The effect of this carburization is similar to the effect of sulfide penetration, in that grains are prematurely separated from the metal surface, and the corrosion rate is increased.

The use of shields for eliminating liquid-phase corrosion was discussed in the previous paper. Operation of these TP-304 stainless-steel shields at 1400–1500 F places their temperature above the molten complex sulfate-formation range and below their rapid gas-phase-attack range and, hence, no appreciable corrosion of the shields occurs. Shielding is still the most effective means known to eliminate rapid liquid-phase attack. No corrosion of shields has been observed after more than three years of service in several boilers of up to 1050 F steam temperature, and tube attack has been eliminated. At scheduled outages, replacement of only a few shields dislodged due to soot blowers and/or to faulty welds has been necessary. Such replacement has averaged less than 1 per cent.

Remedial measures for alleviation of corrosion depend upon the type of attack causing corrosion. Both liquid and gas-phase corrosion produce black iron-oxide scale as the ultimate end product, hence it is easy to confuse the two types. Rapid corrosion of stainless steel used in finishing superheaters and reheaters is almost always the result of liquid-phase attack, and here little question arises as to the remedial measure necessary. Low-chromium ferritics, on the other hand, are always used at temperatures closer to their much lower gas-phase-scaling temperature limits. With these alloys, determination of the type of attack is extremely important in order to apply the proper remedial measures.

Water Treatment

A four paper session offered a variety of subjects pertaining to the treatment of water in general or the equipment employed or affected by this treatment.

"The Relation Between Boiler Cleanliness and Feedwater" by **Frank Urbane Neat,** Baltimore Gas and Electric Co., contained the highly illuminating statement that the ratio of failures to total boilers under any one treatment remains equal, or nearly so, under all the various treatments—caustic, phosphate, amines, etc.—championed by those operating power boilers. Mr. Neat then proceeded to sketch the thinking and the different views on the role of ammonia, volatile alkalies, dissolved oxygen, copper, and welds and welding rings.

If we now have three conditions which are not causes of corrosion but are merely coincident, what, then, said Mr. Neat, are the causes? Actually, he believed there are two causes each of which requires certain conditions to exist. First is generally termed "steam binding." The

second type occurs only in a dirty boiler. The Dowell people at one time stated that no corroded boiler showed less than 0.006-in. scale deposit thickness calculated from the iron content of the drained acid back to the total heat-transfer surface.

There have been several efforts at explanation of the mechanism of the deposition. Johnson and Kehmna of Pacific Gas and Electric Co. indicated that hard or soft deposits depended upon the ratio of copper to iron dissolved in the feedwater. Several Russian papers interpreted by Mrs. Berk, wife of Mr. A. A. Berk of the Bureau of Mines, indicate that deposition depends upon the concentration and rate of heat input, treating the copper and iron separately and indicating that neither affects the other.

At the feedwater cycle and here alone, oxygen gets in its dirty work. Mr. Grabowski and his co-workers made an excellent study of this ("Field Studies of Preboiler Corrosion in High Pressure Steam Plants," H. A. Grabowski, H. D. Ongman, and W. B. Willsey, Proceedings of the American Power Conference, vol. 18, 1956) to illustrate the effect of dissolved gases in various heat-cycle arrangements. One valuable contribution of the paper, the importance of which is still not recognized by many power-plant people, was the demonstration that pH measurements alone have little value in corrosion control where high-purity waters are concerned.

While the power industry has been having its troubles with brass, there has been under its nose all the time a matter of quandary. In view of the fact that in the highest temperature heater, the economizer, all steam-containing shells and all piping are of steel, no one speaks of trouble on the water or steam side of this material. Furthermore, long ago when it was found that turbine steel could be protected with volatile alkalies something should have started wheels rolling. But no major step was taken until the supercritical plant at Philo, Ohio, reported copper in the turbine to the extent of a forced shutdown because of thrust-bearing pressures.

While all this was happening, the company with which the author is associated was planning a once-through Benson-type boiler installation. In looking over all the troubles with copper alloys and reflecting on experience with steel, the author suggested that there be no copper alloys in this design. As far as the stage heaters are concerned, the request was granted. However, the design of the main unit condenser and the foundations for the turbine were so well along that aluminum brass was accepted as the tube material for this condenser, except that all tubes in the air-removal section and in the "erosion" areas will be Type 329 stainless steel.

From this point on the author's comments on steel and the power industry's second look at this material for heat exchangers, and similar other duties seemed of such immediate value we shall publish the paper in its entirety in our March issue.

A. W. Kingsbury and **E. L. Phillips,** The Permutit Co., in their paper "Vacuum Deaerator Design" emphasized that the cold-water vacuum deaerator is finding application in the treatment of industrial waters containing contaminant gases which may interfere with a chemical process or be responsible for corrosion. Hence a study of the operating characteristics of a unit approaching industrial size was made to obtain data which could be used as a basis for practical design for oxygen or carbon-dioxide removal.

The water used in the tests was from a surface supply which varied in temperature from winter to summer and frequently from day to day over a fairly wide range. As there was no practical way of controlling the temperature, it was impossible to hold this factor constant. Under the circumstances, it was necessary to group the test runs in various temperature ranges, using data accumulated over an extended period.

The height of the packing was varied by submerging the Raschig rings to the required level. The amount of degasification occurring in the submerged portion was insignificant.

Sampling was from the discharge of the centrifugal pump at the deaerator outlet. The pump was provided with a water seal from the pump discharge. Alternately, samples were taken directly from the tower through a pipeline extending from a gage-glass connection to floor level.

For the solution of a specific problem in reference to the selection of a required tower height and vacuum pump, a suggested procedure would be to plot the H_2O/NCG (noncondensable gas) ratio versus tower height. The tower height can be calculated from equations and the appropriate HTU and end effect selected.

Robert H. Pell, Monongahela Power Co., then reported on "Performance of Stainless Steel Condenser Tubes." The Rivesville Unit No. 6 of the author's company has a capability of 90,000 kw and went into service Sept. 1, 1951. Steam conditions at the throttle are 1250 lb and 950 F. Steam exhausts from the low-pressure turbine into a Westinghouse two-pass radial flow condenser.

In the evaluation, welded seam 22 Bwg Type 304 stainless steel tubes were chosen. By using the thermal conductivity of Type 304, as recorded by the current HEI (Heat Exchanger Institute) standards, calculations indicated almost equal performance with copper-alloy tubes if the stainless tubes could be kept 85 per cent clean. Other points of consideration were:

1. An expected 30 years life from stainless, compared to seven years for the copper.
2. Welded stainless-steel tubes were within a reasonable price range and appeared to be satisfactory for condenser use.
3. Experimental use of 22 Bwg gave satisfactory results when expanded into the tube sheet.
4. Experience indicated that stainless and the Naval Brass tube sheet could be safely used together without any detrimental effect from galvanic attack.

All tests to determine the performance of stainless-steel tubes have been made in the same manner as the routine tests made on the previous 88-10-2 copper-alloy tubes. No special test equipment has been employed and no artificial conditions established at any time during the testing. Cooling-water flow for each test was calculated by heat balance. The average velocity for each test was then calculated from the cooling water flow and the condenser water pass area. The initial temperature of the cooling water and exhaust pressure were variable but could be recorded, and the cleanliness factor of the tubes could be calculated from each set of test conditions.

It should be remembered that in all of the measurements, the thermal conductivity used for the stinless steel was that given by the HEI standards.

The results of the installation borne out by numerous tests have shown that the actual performance has exceeded original evaluation and expectation.

Design Considerations

A number of papers throughout the program sponsored by several different bodies seemed to us to fit better under the above heading. "Economy of Efficient Air Preheating with Extraction Steam" by **M. K. Drewry,** Wisconsin Electric Power Co., is one such paper.

Extraction feedwater heating has proved of important value to power plant economy and capacity. For ever-increasing higher steam pressures and temperatures the regenerative cycle promises still higher benefits. Heating feedwater in "auxiliary condensers," as extraction heaters were sometimes termed early in their use, will continue to substantially increase the potential capability of sites where condensing water is limited.

For the same temperature rise, combustion air has about one third the heat capacity of feedwater. The heat capacity of air is limited importantly, however, because it is employed to cool flue gases, a function it has assumed after extraction steam heating of feedwater to relatively high temperatures became common. The gains due to efficient extraction steam air preheating, however, are not always negligible.

The major air heater manufacturer's standards recommend 275 F minimum full-load flue-gas outlet temperature when burning mid-western coal, as in the case treated herein. As a result, 275 F appears the minimum practical full-load flue-gas temperature planned for many modern boiler units. This temperature presently influences the top limit to which extraction steam air preheating can be used. Determinations of preheating gains can often logically employ 275 minimum full-load flue-gas temperature as the present practical minimum.

Variously designed "low-level" economizers and air heaters, some arranged for frequent washing, are other means of improving plant heat rate. Flue-gas neutralizing has been the subject of tests to avoid "cold-end" corrosion and clogging. Which method is most practical seemingly depends upon the particular conditions of each application and expecially upon the fuel being burned. In general, low flue-gas temperatures accentuate corrosion and the problems it creates. Experience of the author's company recommends efficient air preheating.

As with extraction feedwater heating, the effect of extraction steam air preheating on all plant components needs be considered. Both feedwater and air heating importantly reduce the congestion in turbine exhaust blading which is becoming a difficult problem as ultimate limits of present metals are reached and as capacities soar rapidly upward. Credit should be taken for reduced costs for the condenser and its circulating water facilities when employing efficient airtype "auxiliary condensers" that use combustion air instead of water for condensing. Under some conditions they can be largely justified on their condensing value alone.

By heating cold combustion air higher than needed to simply keep the main regenerative air heaters acceptably clean and passably free of corrosion, steam air preheaters can insure at all times the development of valuable peak capability and of maximum economy, plus long life of the regenerative air heaters. This avoids the need of recirculating flyash-laden air, with the forced-draft fan erosion and unbalance problems that such recirculation often causes. Steam air preheaters increase steam flow through the high pressure turbine blading for the same electrical output, improving turbine efficiency in the same manner as extraction feedwater heating. Precise comparison with alternatives cannot properly omit these several aspects.

Outdoor boiler plants require more air preheating than do indoor units, thus affording more opportunity for storing cheap heat in combustion air. Compared with heated air recirculation, power savings can be realized if the steam air preheaters expand the air after the forced-draft fans. Air heater leakage is not enhanced, as with recirculation's higher air-inlet pressure. To make exact comparisons for marginal conditions, all these factors deserve evaluation.

Mr. Drewry then described in considerable detail studies applied to his company's Oak Creek Unit No. 5. Efficient air preheating with extraction steam seems to offer worthwhile economies, especially with midwestern coals. In the example cited, confirmed closely by operating experience, the estimated net additional investment is paid by coal savings in slightly less than two years.

Melvin D. Engle, Pennsylvania Power and Light Co., discussed the new plant operator's headache, "Condensing Water—How Does it Affect the River?" Elsewhere in this issue (p. 37) Combustion is publishing one of the many studies the British have had underway for some years.

Since 1956, the Lehigh University Institute of Research under the direction of **F. J. Trembley,** Professor of Ecology, has been conducting research in the Delaware River near Martins Creek, Pa., on the effects on aquatic life resulting from the discharge of the condensing water from the Martins Creek Steam Electric Station of the Pennsylvania Power & Light Co. Some of this work was reported by Combustion, Nov., p. 48, as it was announced before the ESWP Water Conference in Pittsburgh.

The following general conclusions can be drawn from the research done at this location:

1. The condensing water entering a river from the discharge canal of power station usually spreads out on the surface of the river unless rapids, dams, eddies, or other obstructions in the river cause it to mix with the river water. The temperature of the water at the bottom of the river is usually not affected.
2. The distance downstream from the power station where the surface river water returns to normal, will vary with almost every location and depends upon so many variables that no general statement can be made.
3. The botanical growth in the river is not affected, except for a small triangular area starting at the point where the discharge canal enters the river.
4. The chemistry of the river water is not affected, except for a small reduction in oxygen content in a small triangular area starting at the point where the discharge canal enters the river. The loss in oxygen content is never serious enough to adversely affect the aquatic life.

5. Fish have the ability to stay out of areas in the river where the temperature of the water is not to their liking.

6. There are no fish kills in the river resulting from the discharge of the condensing water to the river.

7. In the late fall, winter, and early spring the fish congregate in the warm-water areas of the river caused by the discharge of the condensing water to the river.

8. Fishing is best in the river a short distance downstream from the place where the condensing water enters the river, except for the hot summer months. In fact, in the winter, early spring, and late fall this is the only location in the river where there is any good fishing.

9. The good fishing season in the river is prolonged as a result of the discharge of the condensing water.

10. Overall, fishing in a river is improved as a result of the discharge of condensing water to the river.

11. Local conditions govern the aquatic effects resulting from the discharge of the condensing water from a power plant to a river. Until more complete information is obtained, each case should receive individual study and treatment.

S. J. Kowalski, Philadelphia Electric Co., described the "Ventilation of Eddystone Station—An Approach to Ventilation of Modern Steam-Electric Generating Stations."

Eddystone Station, with its large coal-fired steam generators, turbine-generator units, maze of steam pipes, large number of feedwater heaters, various large motors and hot ducts, emphasizes the problem of heat relief in steam-electric generating stations. The sources of heat are many, are widely distributed, and if not controlled will provide an extremely hot plant in which the operating and maintenance functions become generally difficult and, in localized plant areas, may become impossible.

Three methods can be employed either singly or in combination to provide comfortable temperatures. They are (*a*) general plant ventilation; (*b*) spot ventilation at selected work areas; (*c*) removal of heat at the source to prevent its entry into the plant. An analysis of the design considerations of Eddystone Station was used to illustrate how these three approaches can be used and further provide design criteria for determining the amount of ventilation required for steam-electric generating stations.

Donald R. Baker and **Howard A. Shryock,** The Marley Co., combined talents on the paper "A Comprehensive Approach to the Analysis of Cooling Tower Performance." As they explained, the generally accepted concept of cooling tower performance was developed by Merkel in 1925. His analysis combined the sensible and latent heat transfer into an overall process based on enthalpy potential as the driving force. A number of assumptions and approximations were used by the authors to simplify the development of the final equation. Accuracy is sacrificed as a result of these assumptions and approximations but modifications may be made in the application to minimize the extent of the resulting errors. It seems desirable to the authors to review the development of the basic equation in order to see how it is applied to both cross-flow and counter-flow towers, and to understand how the calculations may be modified to increase the accuracy.

Recently several of the items which constitute an axial pump have been considered both analytically and experimentally. This analysis "An Investigation of Axial-Fow-Pump Design" by **Y. K. Gayed** and **S. Mikhail,** Cairo University, found the method of design is still based on single aerofoil results obtained over twenty years ago, modified perhaps by more recent tests on thin hydrofoils. A procedure which pieces together the results of investigations on blade cascades as affecting the duty and the speed limitations set up by cavitation is still lacking. It is to fill this gap, at least in part, that the present paper is made.

Ever since the National Aeronautics and Space Administration (NASA) first demonstrated an efficient transonic compressor that realized the potential of high flow and high pressure ratio, there has been intense activity to capitalize on this discovery. Private industry and research organizations, including the NASA, have devoted a large amount of effort toward widening this field. The principal function of the paper "Critical Highlights in the Development of the Transonic Compressor" by **R. O. Bullock,** AiResearch Manufacturing Co., is to summarize the important information acquired from single-stage transonic compressor research as the NASA. This source of work was selected because it is the only declassified, published, and coherent information readily available at this time. The secondary function of this paper is to appraise the current state of the art and indicate the outstanding problems and possibilities of transonic compressors.

Steam Cycle Monitoring

A number of papers covering the general area of measurements and cycle studies were sponsored by several different divisions. We regret space limitations make it impossible for us to give these papers at this time. We will, however, run individual abstracts in future issues.

K. C. Cotton and **J. C. Westcott,** General Electric Co., agreed in their paper "Methods for Measuring Steam Turbine-Generator Performance" that the most accurate method of establishing the performance level of steam turbine-generators is to conduct tests according to the ASME Power Test Code and that the accurate instrumentation and procedures required for acceptance tests are quite thoroughly covered in the Code. Their paper, however, described simplified, but admittedly less accurate, methods of obtaining steam-turbine performance testing, and methods of checking the accuracy of acceptance tests.

As a result the authors believe turbine performance can be determined with a minimum of instrumentation from enthalpy-drop efficiency tests. If the turbine section normally operates in the superheated-steam region, these tests can be made accurately. Further investigations are required to evaluate the merits of this method for determining used energy end point of the reheat turbine.

The authors stressed, however, that when this paper was written, they included information and expressed opinions believed to be correct and reliable.

Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Furnace Research and Advancement

Flow Experiments on Models of Boiler Furnaces. F. N. Scheubel. *B.W.K.* 1960, **12** (Aug.), 347–50 (in German).

The problems encountered in the investigations of flow problems in cold models, especially the development of similarity laws, are discussed. The most essential parameters are the Reynolds number and a "dust" parameter characterizing the relative movement of pulverized coal and gas. Experiments are in progress to obtain data of the turbulent mixing process between a dust-laden and a dust-free gas jet. Examples of model tests are presented.

The Factory Fabricated Coal Fired Boiler. L. F. Deming. *Amer. Pwr. Conf.* 1960 (Mar.), 24 pp.

The development of and test results obtained on two boilers, one rated at 12,000 lb/hr, the other at 30,000, are reported. The first is provided with a longitudinal drum, spreader stoker with vibrating grate and cinder reinjection and operated satisfactorily from 4,000 to 14,000 lb/hr with an efficiency of 85.31 at 12,999 lb/hr, but cinder reinjection was unsatisfactory and smoke density high. The other boiler is of the transverse drum type, has a spreader stoker with oscillating grate and was tested with a wide variety of coals up to outputs of 53,568 lb/hr, efficiencies varied with coal and load between 79.63 and 84.85.

Research on Pulverized-Fuel Flames by the International Flame Research Foundation: 1. Summary of Work Carried Out by G. G. Thurlow; 2. Cold Aerodynamic Trials on a Fifth-Scale Model of the Ijmuiden Pulverized-Fuel Furnace by G. Tissandier; 3. The First Performance Trial and First Combustion Mechanism Trial with Pulverized Coal by E. H. Hubbard; 4. Microscopic Examination of Samples taken from a Pulverized-fuel Flame by B. Alpern, P. Courbon, J. Plateau and G. Tissandier. *J. Inst. Fuel* 1960, **33** (Aug.), 366–402.

The first article presents a description of the plant, test procedures used, history of the tests, input variables, results obtained to date and practical application. The second article deals with an analytic and experimental investigation of the problem of predicting velocity and concentration profiles in an enclosed jet system. The third paper details the results of the first test series and discusses the effect of the different variables on flame radiation, temperature and heat transfer and the combustion mechanism. The fourth article describes the examination by the electron and light microscopes of particles taken at various stages from the flame and draws some conclusions on the combustion process derived from it.

Investigations of a Pulverized Coal Flame in a Model. H. Effenberger. *B.W.K.* 1960, **12** (Aug.), 351–5 (in German).

Dried and pulverized brown coal was injected from below into a cylindrical vertical furnace and particle size and air ratio varied. Temperature, gas composition and particle size were measured over the furnace length. The results suggest that all the oxygen required for combustion should be added in front of or at the burner mouth.

Remarks on Research Work on Pulverized Coal Flames. R. H. Essenhigh. *B.W.K.* 1960, **12** (Aug.), 356–8 (in German).

A very brief outline is given of the work on pulverized coal flames carried out in Sheffleld, preliminary results obtained and future research envisaged.

Water-Side Corrosion and Water Treatment

Corrosion in Circulating Water Systems. C. O. Smith. *Brit. Pwr. Engng.* 1960, **1** (Aug.), 61–4.

Occurrence and protective measures are discussed.

Interference of Organic Contaminants with Ion Exchange Processes—Occurrence, Prevention and Cost. H. E. Bacon and W. J. Lewis. *Combustion* 1960, **32** (July), 37–41.

The nature of organic fouling of anion resins is discussed and the various methods for preventing losses listed. It is generally necessary to apply more than one and it is impossible to predict which may be successful in a given case.

Corrosion of Heat-Resisting Alloys in the Presence of Fuel-Oil Ash. Pt. 1. Council of Brit. Manuf. of Petrol Equipment's Corrosion I Ctte. *Brit. Petrol Equip. News* 1959, **7**, No. 4 (Autumn), 54–69.

The effect of various amounts of V and Na and their ratios on the corrosion resistance of ferritic and austenitic steels containing different percentages of Cr, Ni and Fe have been studied. Specimens were exposed to flue gases at Bankside and Haifa power stations and those of the boilers of S. S. Nestor. The ferritic steel (26 per cent Cr) was most resistant to deposits, austenitic steel with low Ni content more resistant to deposits of low V:Na ratio and steels of high Ni content more resistant to deposits of high V:Na ratio. The corrosion mechanism due to the deposits is discussed.

Corrosion by Vanadium-Pentoxide Sodium Sulphate Mixtures in Laboratory Tests: Correlation with Corrosion by Oil Ash in Field Tests. Pt. 2. H. Lewis. *Brit. Petrol Equip. News* 1959/60, **7,** No. 5 (Winter), 48–55.

The laboratory tests on the same steels were carried out with synthetic oil ash and various mixture ratios of sodium sulfate and vanadium pentoxide at temperatures of 650 to 850 C. The results largely confirmed the field tests.

Fire-Side Corrosion in Oil-Fired Boilers. L. K. Rendle, R. D. Wilsdon and G. Whittingham. *Corr. Prev. and Contr.* 1960, **7** (Aug.), 42–5

The second part describes the result of metallographic examination of heat-resistant alloys and presents tables of data on fuel oils, deposit and corrosion rates for low vanadium fuel oils, loss in weight and analysis of scales produced of heat resistant alloys and effect of dolomite injection on corrosion of Swedish superheater steels when firing high vanadium fuel oils.

Flue Gas, Ash and Dust

The Reinjection of Flyash into a Pulverized Coal Fired Boiler. G. Massip. *Chal. et Ind.* 1960, **41** (June), 161–72 (in French).

The installation of a reinjection system for fly ash from the dust collector hoppers and beneath the air preheater in a boiler rated at 92 t/hr at 80 atü and 570 C with roof burners is described. A considerable reduction of combustibles in the fly ash has been obtained and thus the thermal efficiency has been increased.

Intermittent Release of Smoke from Chimneys. J. S. Turner. *J. Mech. Engng. Sci.* 1960, **2** (June), 97–100. Theoretical and experimental studies indicate that a considerable increase in height may be obtained by the smoke if it is ejected in discrete puffs at high velocity. Numerical values for final height, size of chimney, optimum storage and release times are presented.

Industrial Gas Cleaning. N. Pilpel. *Brit. Chem. Engng.* 1960, **5** (Aug.), 542–50.

A review of: (1) Filtration; (2) Electrostatic precipitation; (3) Inertial separation; (4) Washing and wet scrubbing; (5) Agglomeration; (6) Choice of plant.

New Advances in Fly-Ash Control. H. B. Alford. *Combustion* 1960, **32** (July), 45–9.

Due to the improved combustion conditions in modern boilers the ash has a high resistivity and a low SO_3 content so that its precipitation has become difficult. A new "finned" plate has been developed to increase collecting efficiency. Improved rapper controls are described which reduce re-entrainment of collected ash. Automatic controls allow operating the precipitator at optimum efficiency for a given ash; high resistivity ash requires fewer sparks at greater intensity.

Power Generation and Power Plant

Sites for Coal-fired Power Stations. Anon. *Electricity* 1960, **13** (July/Aug.), 204.

Owing to the scaling down of the nuclear power program and forecasts of higher loads for 1965/1966 more coal-fired stations will have to be built. Consent is sought for two 2000 mw stations at West Burton and Holme Pierrepoint and a 1400 mw station at Tilbury. Further stations are likely to be constructed in the West Riding of Yorkshire.

Bandour Power Station. Anon. *Electricity* 1960, **13** (July/Aug.), 217.

The first section of this station consists of a monotube boiler rated at 750 klb/hr at 2432 psi and 1112/1067 F and a 115 mw turbogenerator. The thermal efficiency of the boiler is 93.1 per cent and the nett heat rate 7591 Btu/kwh at M.C.R.

Supercritical Plant at Drakelow "C." Anon. *Electr. Rev.* 1960, **167** (Aug. 19), 296–8.

Two 375 mw units have been ordered for installation at Drakelow "C" station by 1965. The boilers, one of Benson and the other of Sulzer design, will provide 2500 klb/hr of steam at 3650 psi and 1110 F with single reheat to 1055 F. One of the turbines will have one h.p., one i.p. and two l.p. cylinders with a double-flow exhausting into twin condensers, the other quadruple flow l.p. cylinders arranged in double-flow l.p. casings; both are in-line tandem-compound machines running at 3000 rpm with 8 stages of feedwater preheating to 505 F. The generators have hydrogen-cooled (45 psi) rotors and water-cooled stators and a M.C.R. of 375 mw at 0.85 p.f. generating at 19 kv.

The Use of Milled Peat in Large Boilers for the Generation of Electricity. J. F. Cullen. *J. Inst. Fuel* 1960, **33** (July), 317–28.

The experience gained in firing pulverized milled peat in three boilers of German make is described. The first boiler has roof firing and Kramer beater mills, the others corner firing, one H.G.S., the other Keller mills. Auxiliary oil burners are installed to stabilize combustion. The peat with a moisture content of 40–65 per cent is dried in the mill by hot flue gas taken from low down in the furnace to which cold flue gas, hot or cold air are admixed. Slagging difficulties at low moisture content and furnace pulsations at high moisture content were encountered and the countermeasures are discussed. Backfiring in the burners, breakages of the mill hammers, and fouling of the cold-end of air preheaters are commented upon. Various modifications of the boilers and mills were introduced. The tests on the first boiler gave a thermal efficiency of 81.3 per cent at M.C.R. with peat of 54.9 per cent moisture and a C.V. of 1780 kcal/kg.

First U. S. Geothermal Power Plant. Anon. *Power* 1960, **104** (July), 80–2.

Four boreholes at Geysers, Calif., produce 283,000 lb/hr of steam which is passed at 115 psi to a turbine driving a 12.5 mw generator. If experience is favorable a second turbine is to be installed.

New Use for Coal. T. S. Spicer. *Coal Utiliz.* 1960, **14** (July), 12–5.

Pittsburgh has erected a new plant for the drying and burning of sewage sludge. The sludge is heated in tanks for five days at a temperature of 95 F by steam generated in two spreader stoker fired boilers (each rated at 40,000 lb/hr, 125 psi, 400 F); the sludge floats to the top and leaves a clean effluent. The warm odorous air from the tanks is used as combustion air to destroy the smell. The sludge with 18–20 per cent solids content is pumped to feed tanks, mixed with dry sludge in a mixer and dried in dual-cage mills by hot gases at 1000–1300 F. The dry sludge is then burned in an incinerator assisted by firing of pulverized coal, the hot combustion gases are used to dry the sludge and are returned also to destroy their smell. Fly ash from the incinerator is separated in a cyclone, reinjected and removed in the molten state.

Slag Tap Boiler Performance Associated with Power Plant Fly Ash Disposal. H. M. Rayner and L. P. Copian. *Amer. Pwr. Conf.* 1960 (Mar.), 30 pp.

Western Electric Co. installed a Turbo Furnace boiler rated at 250 klb/hr at 900 psi and 835 F with slag tap to convert the ash of this and three other, dry-bottom furnace boilers into slag. The boiler is able to operate from 65,000 to 250,000 lb/hr with molten slag removal. The results of tests with no reinjection and with reinjection from one, two and three boilers are tabulated and discussed. Curves of dust loading before and after the collector are presented.

Dungeness Nuclear Power Station. Anon. *Nucl. Pwr.* 1960, **5** (Aug.), 66.

The sixth nuclear power station to be built at Dungeness will have an output of 550 mw produced in two reactors with a thermal output of 840 mw each at an efficiency of 32.9 per cent. The CO_2 inlet temperature is 250 C, the outlet temperature 410 C. Steam is produced at 1410 psi and 392 C and at 550 psi and 391 C with a feedwater temperature of 180 C. There are 3876 fuel channels with 7 elements each per reactor. The steam is passed to 4 main turbogenerators, each of 142.5 mw output.

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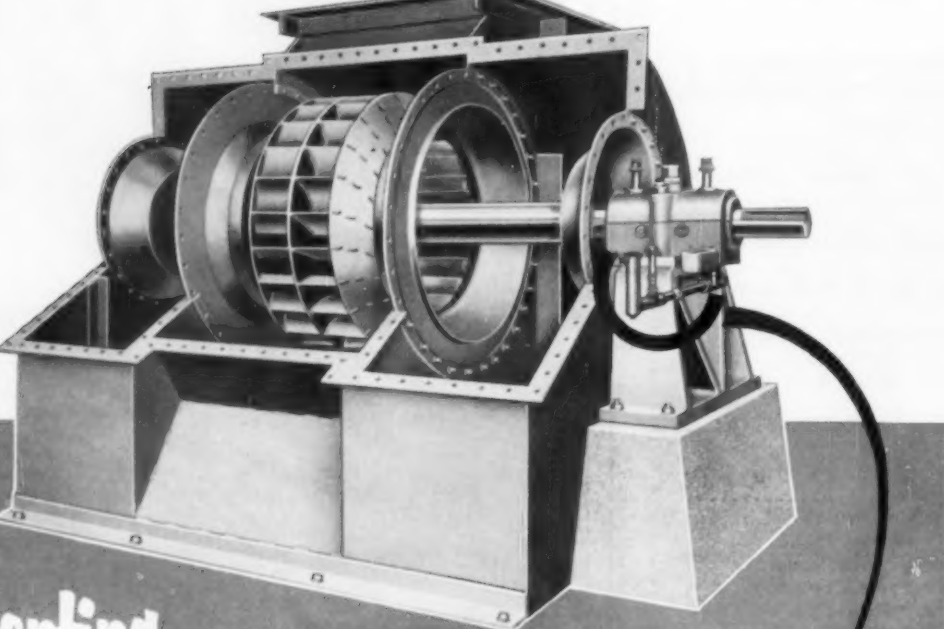

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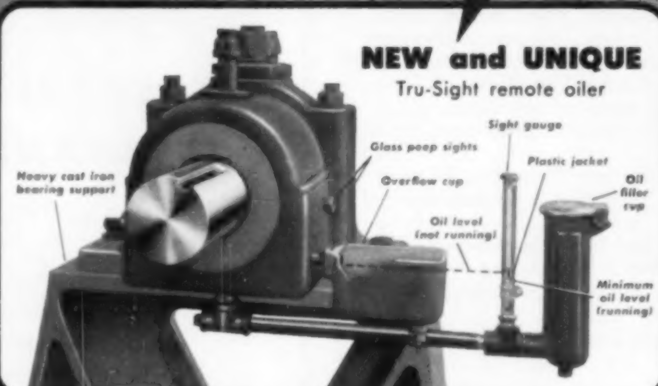

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